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Performance of the Stoker Fired Steam Generators

Interagency Energy/Environment R&D Program Report

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16. ABSTRACT

The report describes the thermodynamic and mechanical performance and corrosion evaluation of the stoker boilers while burning RDF as a supplemental fuel with coal. It can be stated that refuse derived fuel (RDF) may be successfully fired in these stoker boilers with no insurmountable problems. A high refuse fuel utilization was encountered: up to 50% RDF on a heat input basis has been successfully fired. Based on the current method of RDF injection, high excess air flow rates were encountered. Ultimate fouling of the superheater section of boiler No. 5 was experienced. Calculation of the fuel fouling index would seem to verify this behavior. Soot blowers will be installed to reduce this behavior.

There was no trend of change in the percent of the total boiler heat input lost in the ash versus percent RDF heat input. The burn out of RDF was equivalent to that for coal. Corrosion tests conducted to date indicated there was no increase in corrosion due to burning RDF.

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Part II: Performance of the Stoker Fired Steam Generators

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory-Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

On August 30, 1975, the first continuous full-scale, solid waste recovery system for the processing and burning of municipal solid waste as a supplementary fuel for power generation commenced operation in the City of Ames, Iowa. This report provides the results from the study of the performance of the stoker fired steam generators at the City of Ames. The results and/or conclusions of this report may be utilized to determine what problems might be encountered when converting from burning coal only to coal plus refuse derived fuel and to determine what might be done to avert or reduce those problems. The information contained herein will be of interest to those designers or users who are contemplating or working with a system similar to Am[illegible]. Requests for further information regarding performance of stoker fired steam generators utilizing refuse derived fuel should be directed to the Fuels Technology Branch, IERL, Cincinnati.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

PREFACE

The project entitled "Evaluation of the Ames Solid Waste Recovery System" encompasses such a large scope of work and has generated such a large amount of data that the annual report on year 01 is divided into three parts.

Part I, entitled "Summary of Environmental Emissions: Equipment, Facilities, and Economic Evaluations" provides a summary of the environmental emissions and boiler performance of stoker fired boilers burning refuse derived fuel (RDF) and coal; characterization of the RDF produced by the processing plant; processing plant and equipment performance evaluations; and an economic analysis of the processing plant.

Part II, entitled "Performance of the Stoker Fired Steam Generators" evaluates the thermodynamic and mechanical performance of the stoker boilers while burning RDF as a supplemental fuel with coal.

Part III, entitled "Environmental Emissions of the Stoker Fired Steam Generators" is presented in two volumes. Volume I includes the results and discussion, while Volume II includes appendices of data tabulations. The report includes sample analysis of the input and output streams associated with the operation of the stoker fired boilers while burning coal only and coal plus RDF; characterization of the fuel (coal and RDF), ash and stack effluents; and statistical analysis of the data.

The portion of the project covering environmental emissions from the stoker boilers is jointly funded by the Environmental Protection Agency (EPA) and the Department of Energy (DOE). These results are published jointly by both agencies in Part III.

The balance of the project is funded by the EPA and these results are published in Part I and Part II.

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The system evaluation of the Ames Solid Waste Recovery System is a major research program funded by the EPA, and ERDA* with earlier additional participation by the American Public Power Association (APPA). This project is being performed jointly by the City of Ames, Iowa; Engineering Research Institute of Iowa State University; Ames Laboratory/ERDA; and Midwest Research Institute (MRI). This report presents the results and conclusions of the investigation on the stoker fired steam generator units Nos. 5 and 6, and it includes contributions from all of the above participants.

The EPA-sponsored portion of the program was directed by Mr. Carlton C. Wiles of the Municipal Environmental Research Laboratory, Solid and Hazardous Waste Research Division, Office of Research and Development; and Mr. Robert Olexsey, Industrial Environmental Research Laboratory, Office of Energy, Minerals and Industry.

Individuals charged with responsibility for major implementation of the various tasks in this research program are listed below.

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In addition, there were several others who helped during portions of the various phases of the project. These names are too numerous to mention, but the efforts were greatly appreciated and their contribution is hereby acknowledged.

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*During the conduct of the study, ERDA became the U. S. Department of Energy (DOE). Hereafter in this report, the agency which is now DOE will be referred to as ERDA.

SECTION 1

INTRODUCTION

The Ames Solid Waste Recovery System is a continuously operating system that is processing municipal solid waste (MSW) for use as a supplemental fuel in the existing steam generators of the Ames Municipal Power Plant. This system consists of a nominal 136-Mg/day (150-ton/day) processing plant, a 454-Mg (500-ton) Atlas storage bin, pneumatic transport systems and the existing municipal power plant. The processing plant incorporates two stages of shredding, ferrous and nonferrous metal recovery and an air density separator. The three steam generators consist of one pulverized coal tangentially fired unit (No. 7), two spreaders, return traveling grate, and stoker fired units (Nos. 5 and 6).

The EPA Grant No. R803903-01-0 for the 1st year of research study of the Ames Solid Waste Recovery System was officially awarded February 4, 1976. A detailed work plan was submitted in March 1976, and included: (a) environmental evaluations of steam generator units Nos. 5, 6, and 7, including the particulate collector; (b) boiler performance study; (c) boiler corrosion studies; (d) economic evaluation of the solid waste process plant and of the city power plant; and (e) interim characterization of the RDF.

This report concerns itself with the determination of the following objectives:

- Evaluation of boiler efficiency.
- RDF fuel utilization.
- Particulate collector efficiency.
- Other boiler performance behavior including excess air flow, characterization of coal, RDF, grate and collector ash including major chemical analysis, ash softening temperatures and calculation of slagging and fouling indices.
- Corrosion experience.

The actual studies commenced June 1, 1976. Because of boiler unit availability at the power plant, major research emphasis was on the environmental evaluation and boiler performance of the stoker fired units Nos. 5 and 6, while firing coal and coal-RDF.

This report will present results and conclusions of the tests performed on the stoker fired units during June 1, 1976, to September 1, 1976. A separate report on the evaluation of the refuse processing plant (1) has been prepared. A detailed report on the boiler environmental emissions will be submitted separately.

---

(1) Even, J. C., S. K. Adams, P. Gheresus, A. W. Joensen, J. L. Hall, D. E. Fiscus, C. A. Romine. Evaluation of the Ames Solid Waste Recovery System. Part I: Summary of Environmental Emissions: Equipment, Facilities and Economic Evaluations. Engineering Research Institute, Iowa State University, Ames, Iowa 50011. October 1977.

SECTION 2

PROJECT ADMINISTRATION

The involvement of various research organizations and funding agencies on this project resulted in organizational arrangement as shown in Figure 1. Specific tasks are directed and monitored by the principal investigators who are required to forward results as developed. These data were forwarded to MRI for use in their preparation of monthly and quarterly progress reports. These reports were then forwarded to EPA through the City of Ames project manager. MRI was also charged with the responsibility of comparing data results with those resulting from the EPA--St. Louis--Union Electric Company demonstration facility. Ames Laboratory/ERDA was responsible for development of any new analytical techniques and the major share of analysis of collected species. Additional analysis of coal, RDF, and ash was performed by the Research 900 and the ACU-Laboratories.

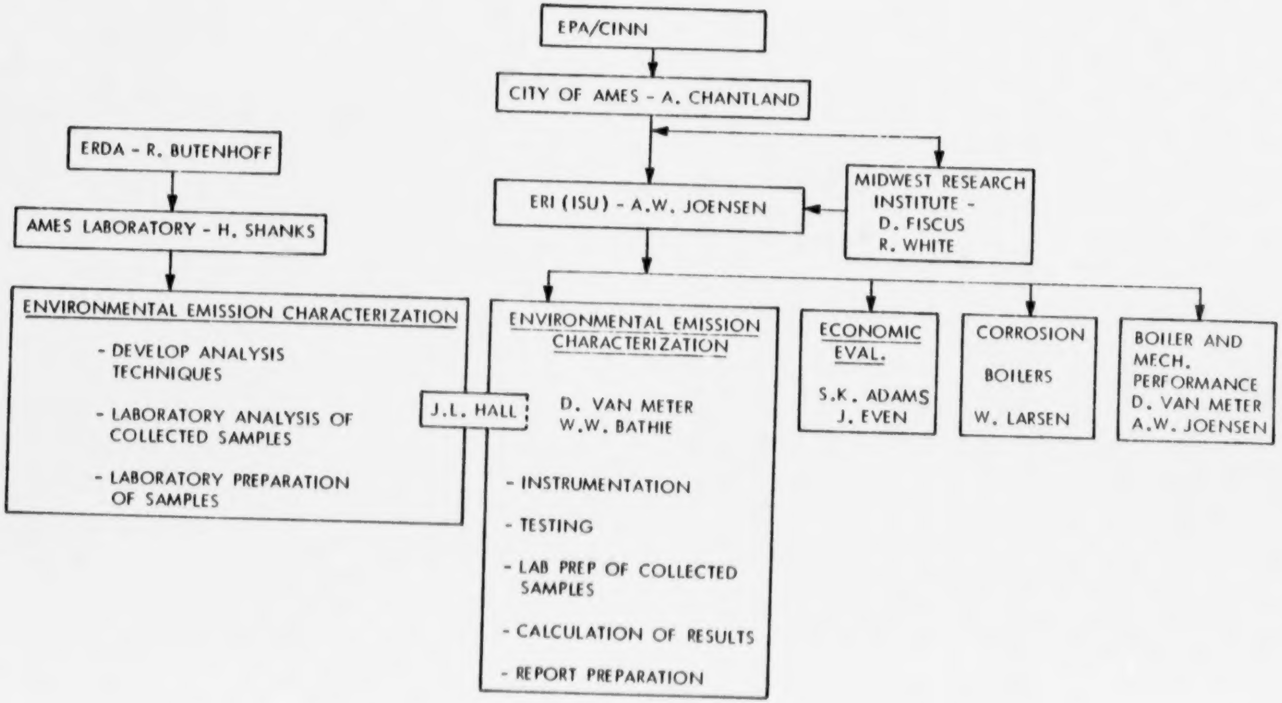
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Figure 1. Organizational diagram.

SECTION 3

SYSTEM DESCRIPTION

The Ames power plant consists of three turbine-generator (T-G) units with their respective steam generators. Boiler units Nos. 5 and 6 discharge into a common steam header such that the steam output from boiler No. 5 can supply T-G No. 6, and vice-versa if necessary. Unit No. 7 operates as a separate unit. A general flow arrangement for all three units is shown in Figure 2.

All references to unit designation which follow in the report allude to the steam generator.

Unit No. 5 is a Riley type RP steam generator rated at a continuous steam flow of 43,000 kg/hr (95,000 lb/hr), 4,340 kPa gage/440°C (630 psig/830°F) with feedwater supplied at 170°C (340°F). Riley Company overthrow coal spreaders (four each) are used along with a continuous return traveling grate. Although this unit was designed for front furnace wall natural gas firing, difficulty in control of steam temperatures forced abandonment of this operational mode several years ago. A single hopper located in the boiler convection pass is used to collect cinders and these are reinjected into the furnace by use of a separate cinder air return fan. An elevation cross-section view is shown in Figure 3. The forced draft fan and combustion inlet is located in the basement. The induced draft fan is located just above the operating floor and above the mechanical fly ash collector.

Unit No. 6 is a Union Iron Works steam generator with a design continuous steam flow rating of 57,000 kg/hr (125,000 lb/hr). Coal feeding is provided by a Hoffman Company underthrow spreader with a continuous return traveling grate. Rated steam conditions are 4,340 kPa gage/440°C (630 psig/825°F) when feedwater is supplied at 180°C (350°F). Hoppers located both under the boiler convection pass and the economizer section collect cinders or combustible carryover for reinjection into the furnace. Cinder return air is supplied from the overfire air fan. The forced draft fan is located in the basement and the induced draft fan is located 17 m above the operating floor. Mechanical dust collectors are used to remove fly ash and are located 13 m above the main floor. A general arrangement is shown in Figures 4 and 5.

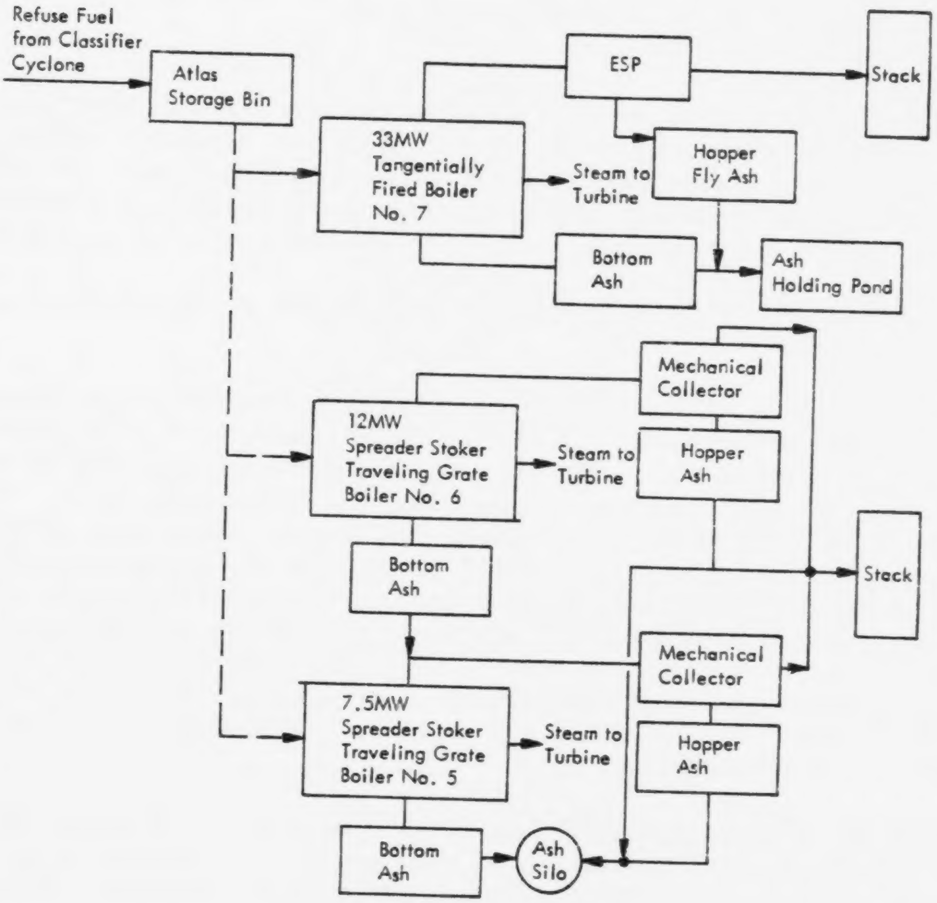

Figure 2. Power plant flow diagram.

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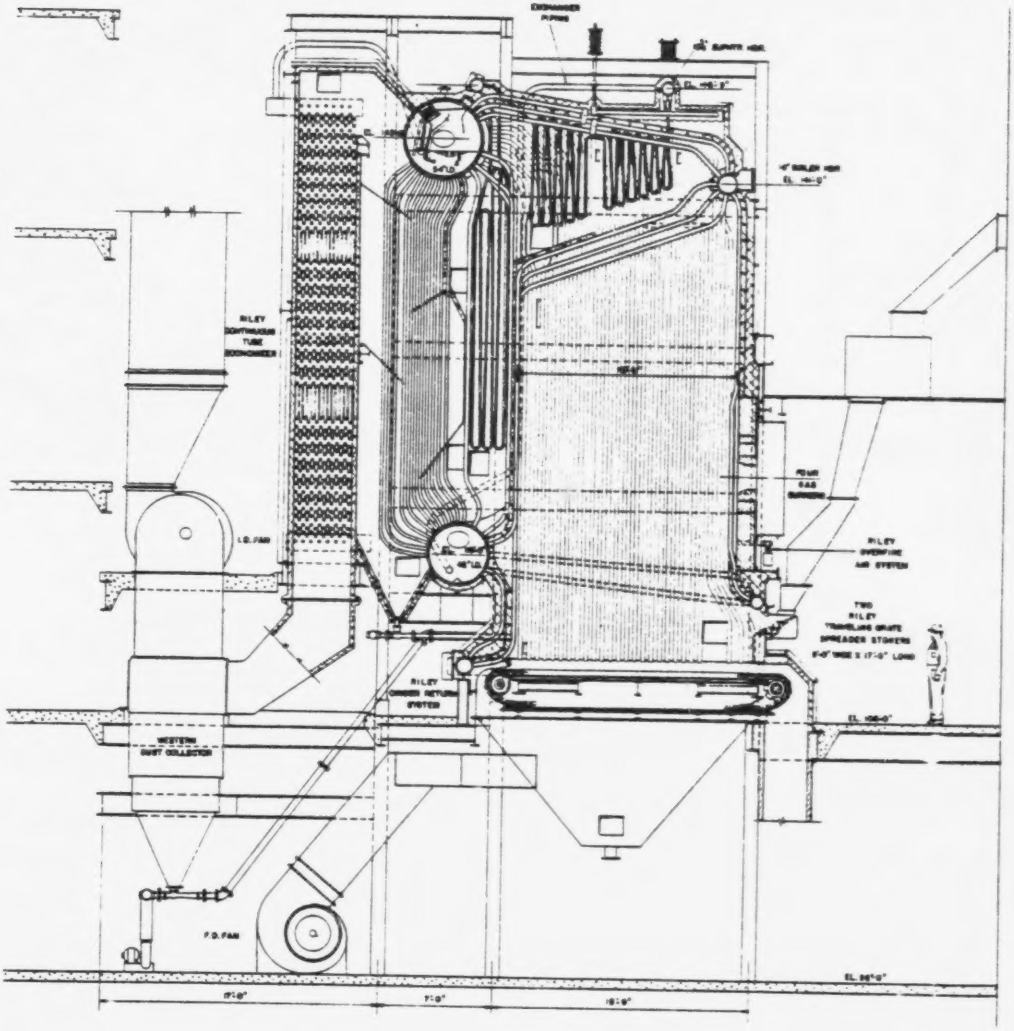
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RILEY OVERFIRE AIR SYSTEM
TWO RILEY TRAVELING GRATE SPREADER STOKERS
RILEY CINDER RETURN SYSTEM
WESTERN DUST COLLECTOR
F.D. FAN
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Figure 3. Elevation view of boiler No. 5.

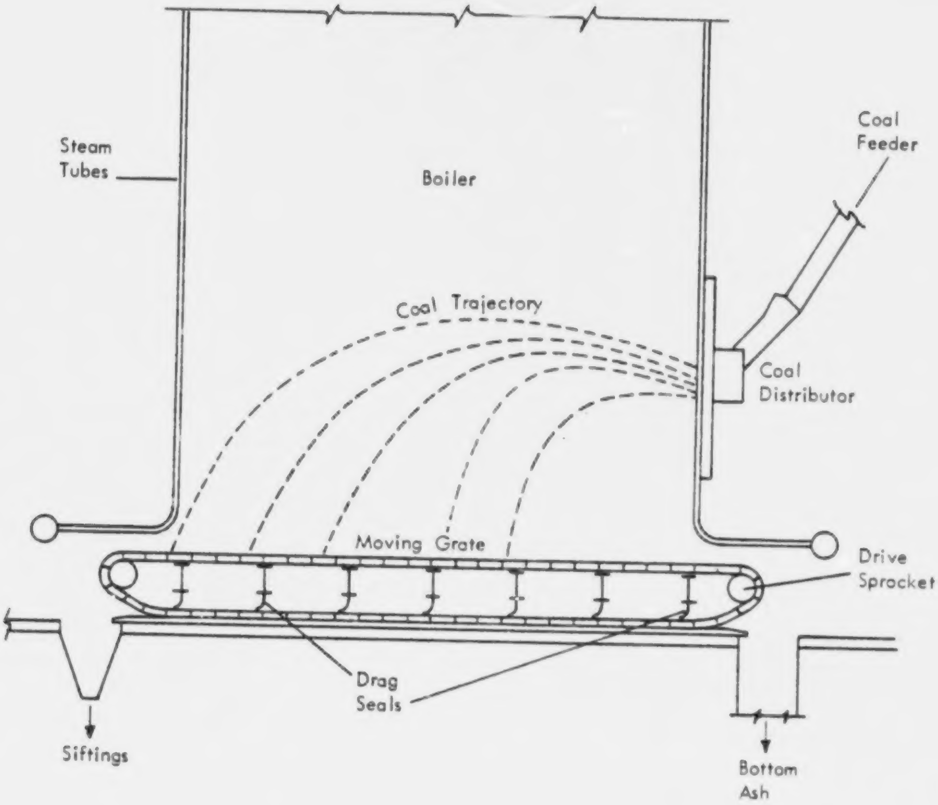

Figure 4. Elements of a spreader stoker.

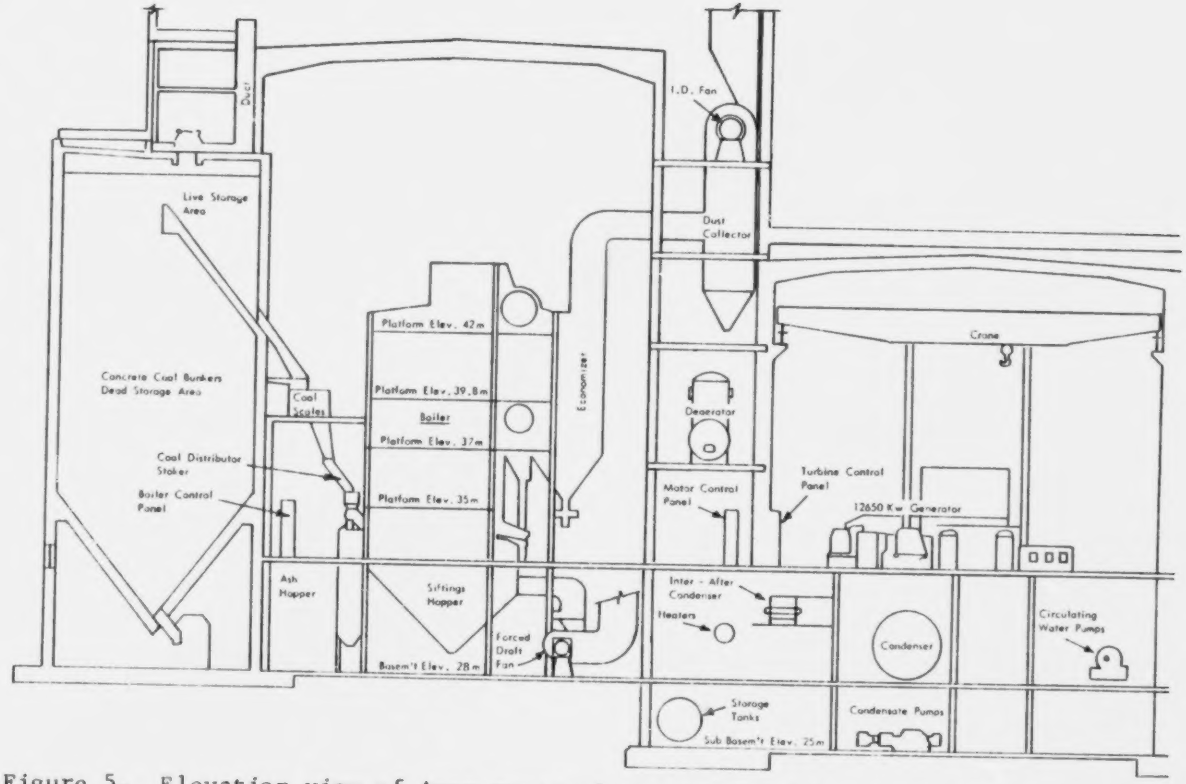

Figure 5. Elevation view of Ames power plant sectioned through boiler No. 6.

Four natural gas burners are located in the furnace sidewall, two on each side arranged in staggered positions. Gas firing is normally used during the summer when economical interruptible (or dump) gas is available. A detailed listing of design data is tabulated in Appendix A.

Both units Nos. 5 and 6 utilize a pneumatic vacuum (or dry) bottom and fly ash removal system. A United Conveyor Corporation pneumatic system conveys ash from grate hoppers, grate sifting hoppers, mechanical fly ash collectors (multiclove), and stack dropout ash to a tiled storage silo located on the east side of the plant. The ash storage bin is emptied once daily. A flow schematic is shown in Figure 6.

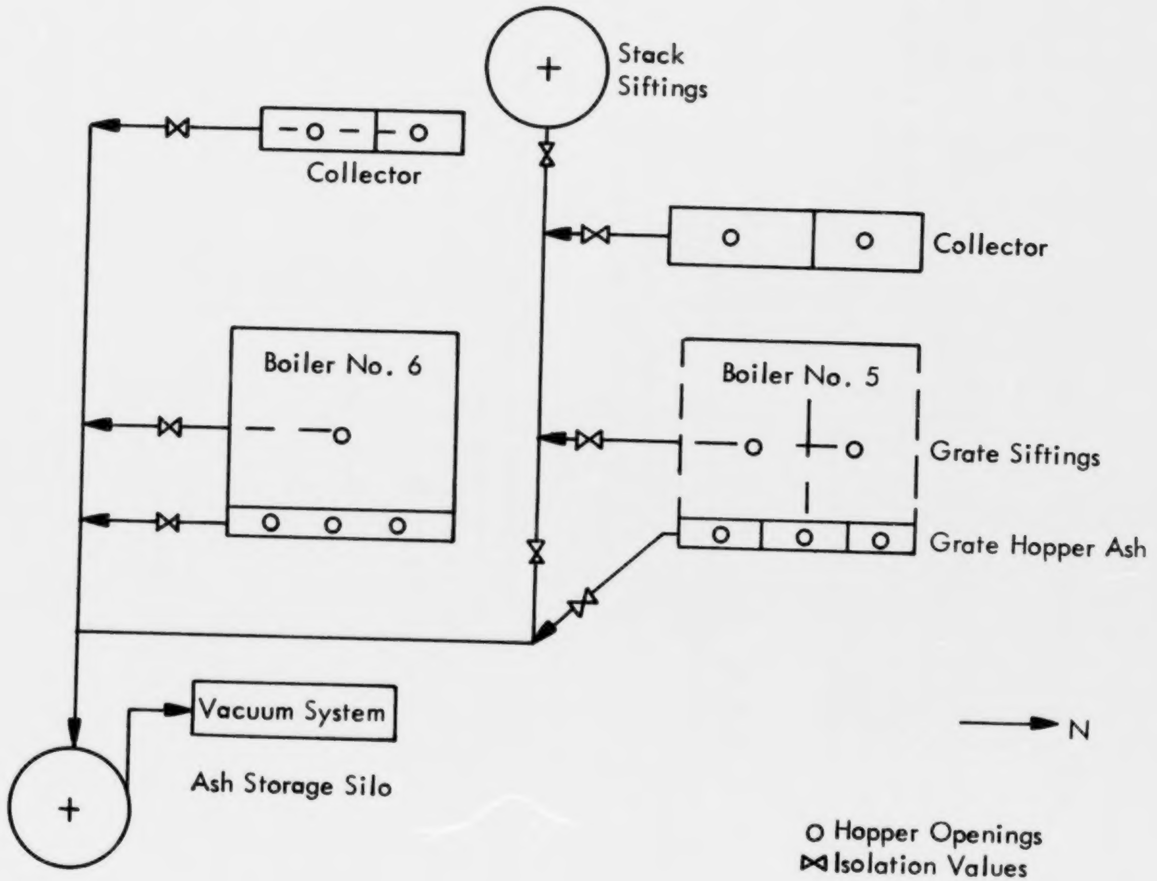

Figure 6. Plan view flow diagram - pneumatic ash removal system.

SECTION 4

POWER PLANT MODIFICATIONS - RDF FIRING

Refuse derived fuel can be pneumatically conveyed from the Atlas storage bin through any of four 203-mm transport pipelines to boiler Nos. 5, 6, and 7. A flow diagram of this pneumatic transport system is shown in Figure 7. The transport pipelines are labeled A, B, C, and D. Each line was designed to convey approximately 3.6 mg/hr (4 ton/hr). Lines A, B, C, and D can also supply RDF to unit No. 7.

Lines A and D are used to supply RDF either to unit No. 5 or 6. Extreme wear encountered in operation resulted in the use of straight spool inserts instead of the diverter valve. Thus, if it is desired to switch RDF firing from unit No. 5 to unit No. 6 or vice-versa, different geometry inserts must be installed. RDF is fired on a continuous basis until the Atlas storage bin is emptied.

Riley Corporation pneumatic distributors are used to inject RDF directly into the furnace of each unit. Two distributors with fan, silencer, and piping were installed in the front furnace wall of each unit. Distributor construction details are shown in Figure 8.

The two distributors for unit No. 5 were installed in the front waterwall area formerly occupied by the gas burners. Unit No. 6 required more extensive front wall modification for installation of the RDF distributors.

Part of the required combustion air (known as overfire air) is introduced through the back and front furnace wall region just above the grate area. This overfire air promotes mixing and turbulence so as to allow complete combustion to occur.

The original overfire air system for unit No. 5 utilized a single row of nozzles in the rear wall and also in the front wall. In addition, the four Riley coal spreader assemblies use an upper plate which is perforated to allow injection of overfire air which also aids in distribution of coal. A separate 4 liters/sec cinder return air fan provides for reinjection of cinders into the furnace.

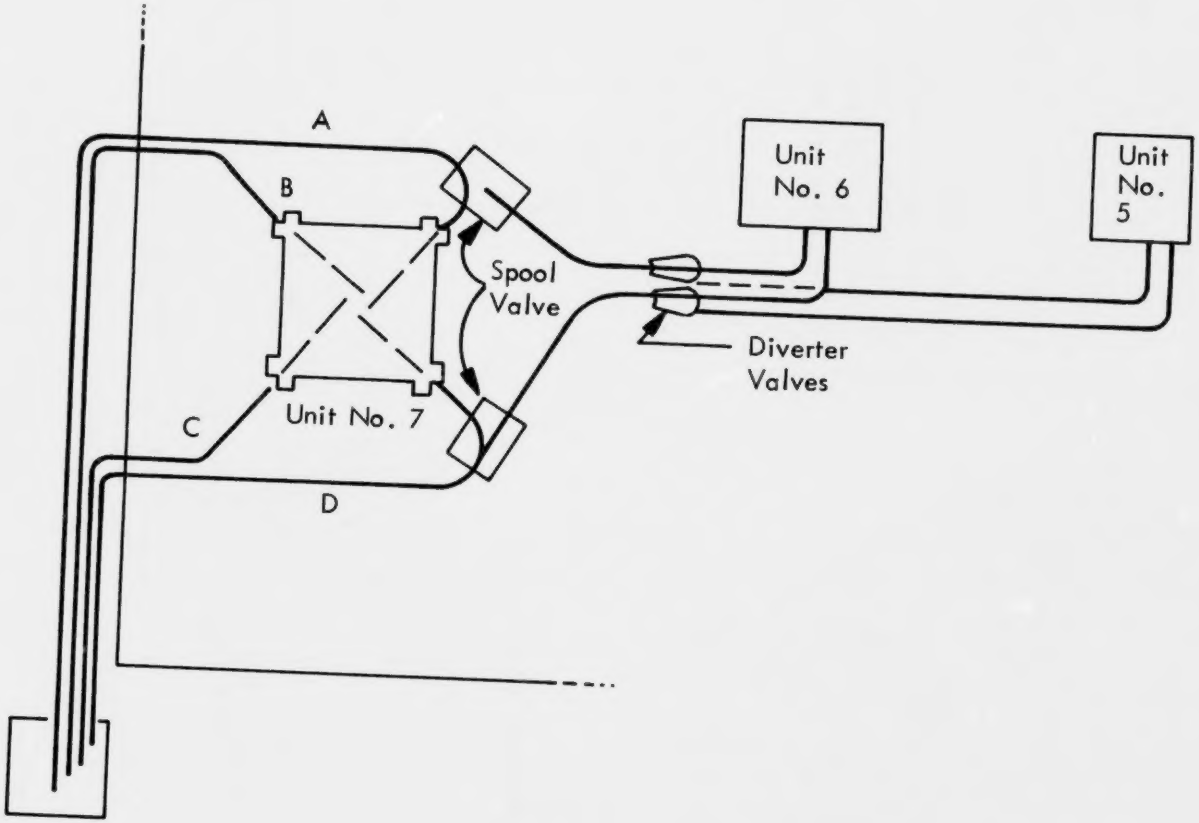

Figure 7. Power plant pneumatic transport system.

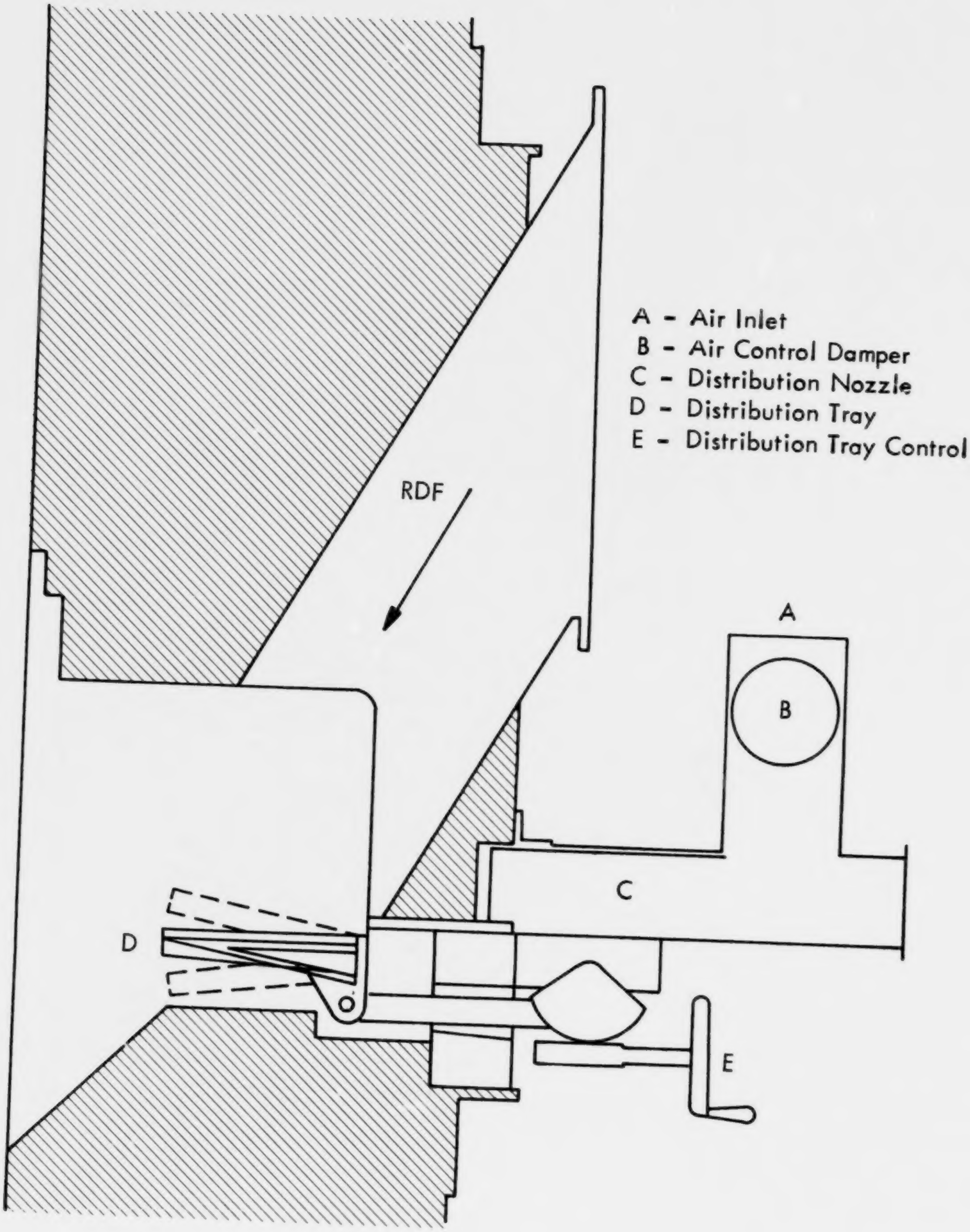

Figure 8. Riley pneumatic stoker.

The modification provided for two sets of rear overfire air nozzles, eight upper and seven lower. The cinder return fan was retained. A set of eight upper nozzles was installed at the original front wall elevation. A larger overfire air fan silencer with appropriate piping was also required. A general arrangement is shown in Figure 9.

The unit No. 6 overfire air system utilized two rows of nozzles in the back wall with a set of seven cinder return nozzles. A set of nine front wall nozzles was located just below the Hoffman coal spreaders.

The modification resulted in two back wall sets of 13 nozzles each, and an additional set of 15 upper front wall nozzles. The lower set of nine lower front wall nozzles was retained. The arrangement for unit No. 6 is shown in Figure 10.

The distributor air system for each boiler uses two sets of nozzles. An upper nozzle (or orifice) is positioned in each of the Riley pneumatic distributors. Its original purpose was to inject RDF into the furnace. A lower set of four distributor air nozzles is positioned below the pneumatic distributor.

Operation over a time period resulted in a buildup of the deposits on the back wall. Current firing practice does not use any of the distributor air nozzles in either boiler. The movable pneumatic distributor plate was positioned in the down position to try and reduce any major back wall impact. Therefore, only pneumatic transport line air is used to inject the RDF into the furnace.

Performance specifications for operation after modification are tabulated in Appendix B.

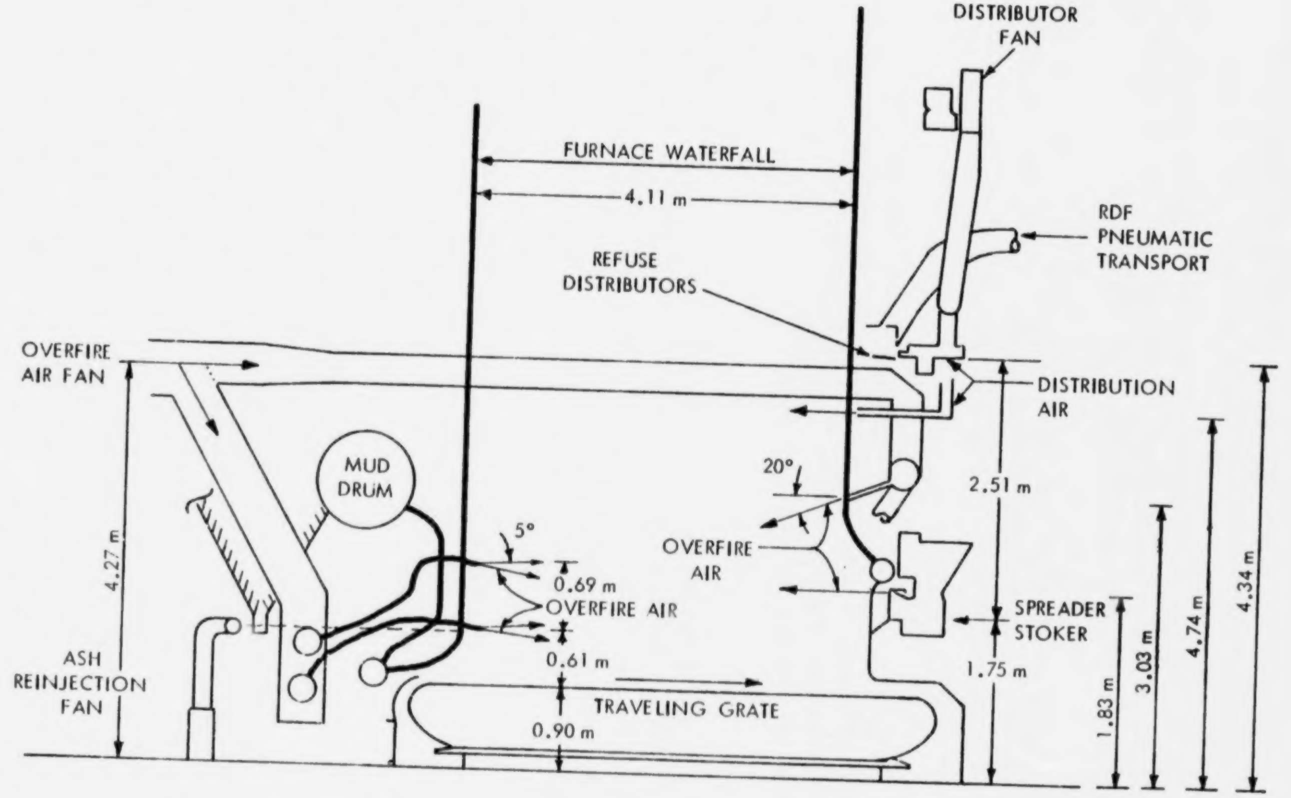

Figure 9. Modified traveling grate stoker fired boiler No. 5.

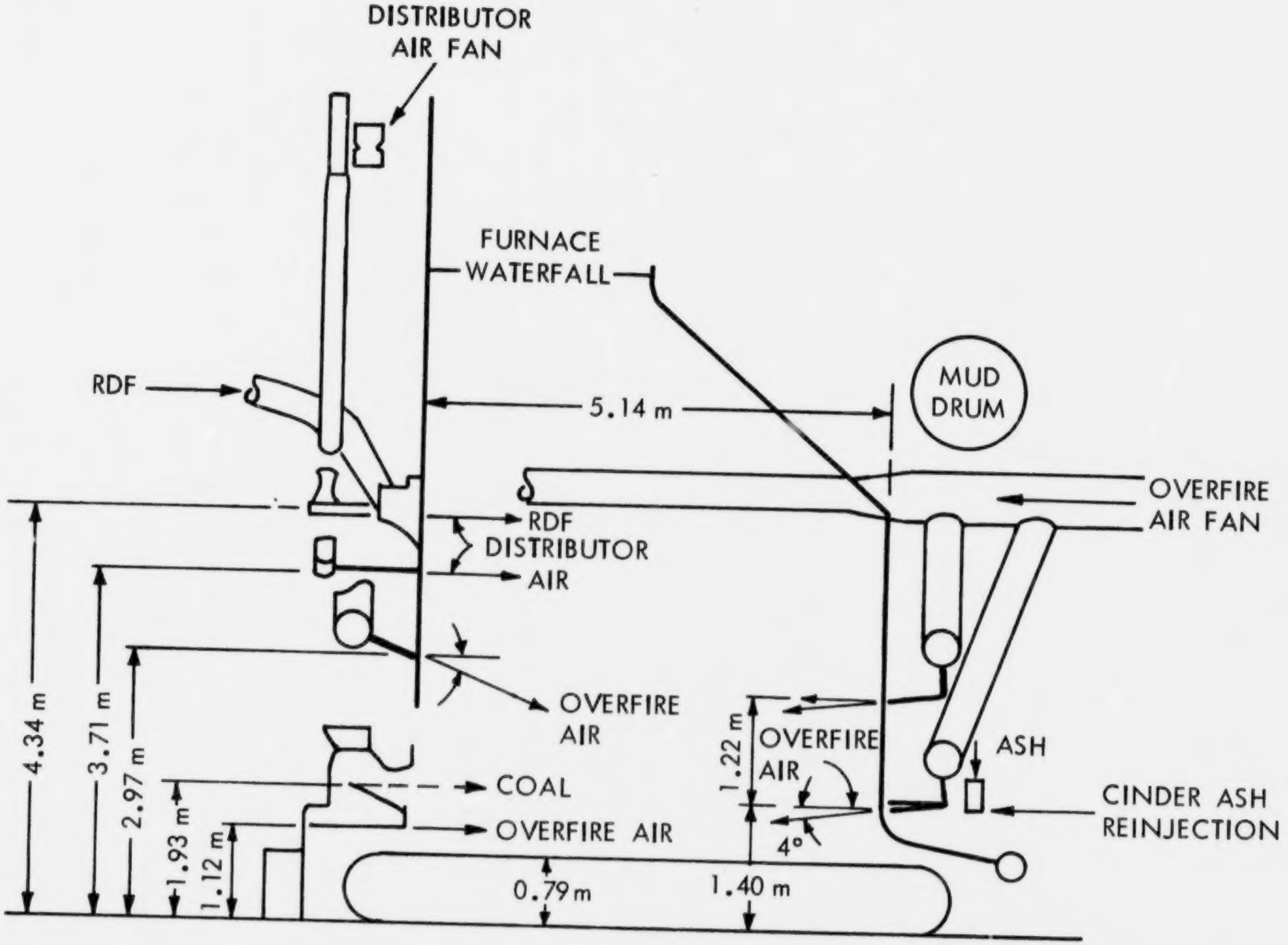

Figure 10. Modification spreader traveling grate stoker boiler No. 6.

SECTION 5

TEST PROCEDURE

The amount of testing and sampling required to effectively characterize the operation and effluents of the power plant is an important consideration. The amount of data required dictates the testing time, number of people required, and the analytical resources necessary to respectively accomplish testing, analysis of results, and correlation of the measured variables with factors which can be controlled in the power plant.

In this study, it was determined that two major factors could be controlled at various levels. These factors were the load based on steam flow and the amount of RDF based on heat energy input in the boiler. The levels of these factors were chosen to be 60, 80, and 100% nominal load, and 0, 20, and 50% RDF. A factorial experimental design with three replications was devised for each boiler as summarized in Table 1. Thus, for boiler unit No. 5 the statistical design is a 3 x 3 x 3 full factorial experiment with 27 runs needed to fill the data matrix of this experiment. In addition, testing of two different size (and design) traveling grate stoker fired boilers (units Nos. 5 and 6) was accomplished at one load setting (80%) to obtain a relative size comparison for all emission data at a given fixed load. The tests accomplished to date are shown in Table 1.

Since the Ames Municipal Power Plant is an operating facility, the appropriate test loads for any test day were based on the actual plant loading that existed throughout the summer; these loads were extremely dependent on weather conditions.

The input fuel flows and boiler load were held as constant as possible; thus, steady-state conditions were attained prior to start of a test. Storage hoppers containing grate (bottom), collector (fly), and siftings ash were emptied prior to the start of each test.

Iowa coal was used for unit No. 5 since the sulfur content is generally higher than that found in Wyoming coal. This single coal was used to reduce potential variation in coal properties that could result from the mixing of Iowa and Wyoming coals. Since RDF is nominally low in sulfur content, it was

TABLE 1. SUMMARY OF FACTORIAL EXPERIMENTAL DESIGN
SHOWING TEST DESIGNATION

Stoker Boiler No. 5 Coal Used: Iowa			
% Load / % RDF	60	80	100
0	4A, 4B 20 21[a] 36	5 16 17	11 31[b] 32[b]
20	8 9A, 9B 33	6 12 13	7 14 19
50	1 34 35	2 10 15	3 18 [c]

Stoker Boiler No. 6 Coal Used: Mixture of 50% Iowa, 50% Wyoming	
% Load / % RDF	80[d]
0	24 29 30
20	25 26 27
50	22 23 28

---

[a] Test 21 conducted while pulling ash from boiler to determine any change in performance and/or emissions due to ash removal.

[b] Bottom ash not weighed because of ash removal difficulties (slagging in boiler and clinkering of ash).

[c] Boiler No. 5 cannot operate at 100% steam load and 50% RDF without severe ash problems due to lack of excess air. Therefore, the third test in series was not conducted.

[d] Load was changed from the originally planned 100% to 80% steam load to be more typical of capability of boiler and air supply for refuse burning. This change was essential from experience gained during testing of Boiler No. 5.

desired to learn if stack sulfur emissions could be reduced substantially by the use of an Iowa coal plus RDF fuel mix.

After equilibrium operating conditions were reached, all necessary pre-surveys were completed for the required environmental sampling evaluation. Normal actual test time for data acquisition was 4 to 5 hr and this was necessary for completion of the environmental sampling. Results of the environmental study are being prepared as a separate joint EPA-ERDA agency report.

During a test on either unit, samples were obtained at all points shown in Figure 11. Coal, RDF, and grate ash samples were obtained at 1-hr intervals and then mixed to yield a composite sample. All stack effluents were sampled according to EPA prescribed procedures.

Coal samples were collected at the discharge of the conveyor belt into a 90-kg kopper scale, located immediately above the boiler coal feed distributor.

Grate ash was sampled laterally across the traveling grate as it dumped the ash into the bottom hopper. Collector (fly) ash was periodically sampled from a bottom opening as the ash was vacuum removed after the completion of the specific test.

RDF samples were obtained at the storage bin by inserting a fixed-volume container below the drag conveyor as it dropped the RDF down into the air-lock feeder of the pneumatic transport line.

Grate and collector ash flow rates were measured in the following manner. Prior to the official start of the test, with the unit at the desired load, all ash hoppers were emptied, and in turn, the ash storage silo was emptied. At test completion, grate ash and collector ash were removed or "pulled" separately. Separate removal of the grate ash from the bottom hopper into the ash silo allowed for truck removal and subsequent weighing at the RDF process plant scale. Collector ash removal was then completed with subsequent weighing. As bottom grate ash or collector ash was removed from the ash silo it was sprayed with water to control dust. This water flow was metered and the weight was deducted from the total amount weighed.

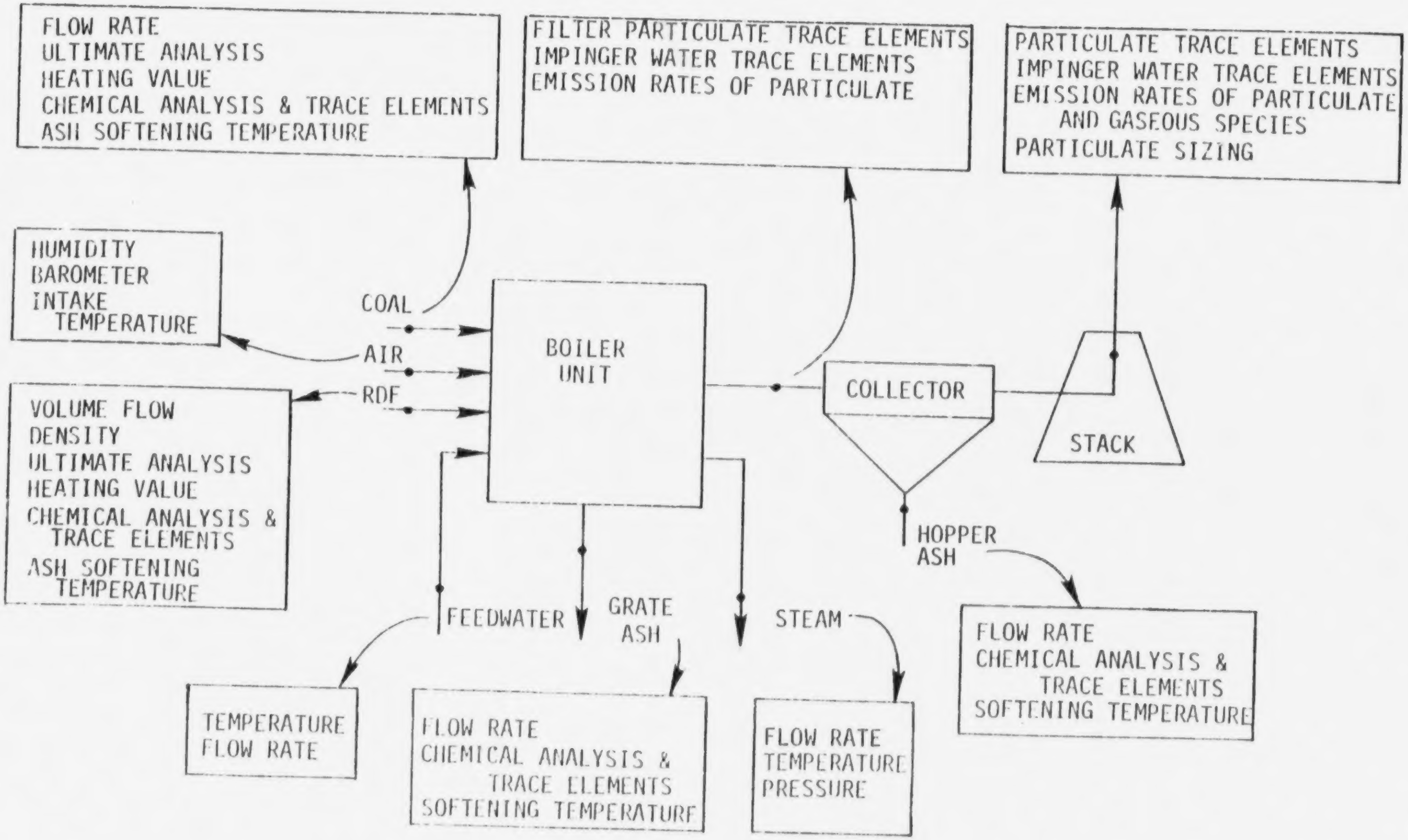
FLOW RATE
ULTIMATE ANALYSIS
HEATING VALUE
CHEMICAL ANALYSIS & TRACE ELEMENTS
ASH SOFTENING TEMPERATURE
FILTER PARTICULATE TRACE ELEMENTS
IMPINGER WATER TRACE ELEMENTS
EMISSION RATES OF PARTICULATE
PARTICULATE TRACE ELEMENTS
IMPINGER WATER TRACE ELEMENTS
EMISSION RATES OF PARTICULATE AND GASEOUS SPECIES
PARTICULATE SIZING
HUMIDITY
BAROMETER
INTAKE TEMPERATURE
COAL
AIR
RDF
BOILER UNIT
COLLECTOR
STACK
VOLUME FLOW
DENSITY
ULTIMATE ANALYSIS
HEATING VALUE
CHEMICAL ANALYSIS & TRACE ELEMENTS
ASH SOFTENING TEMPERATURE
HOPPER ASH
FEEDWATER
GRATE ASH
STEAM
FLOW RATE
CHEMICAL ANALYSIS & TRACE ELEMENTS
SOFTENING TEMPERATURE
TEMPERATURE
FLOW RATE
FLOW RATE
CHEMICAL ANALYSIS & TRACE ELEMENTS
SOFTENING TEMPERATURE
FLOW RATE
TEMPERATURE
PRESSURE

Figure 11. Boiler unit Nos. 5 and 6 sampling locations.

SECTION 6

OPERATIONAL NARRATIVE

As testing progressed throughout June and July, a buildup of ash and subsequent plugging occurred in the slag-screen tube area of unit No. 5 at the inlet of the superheater. Beginning on July 23, 1976, "puffing of gases" emanating from furnace openings began to occur. In an earlier test at 20% RDF flow, there were several instances when the furnace draft (gage) pressure went positive yet no flue gases would be emitted from the furnace openings around the spreaders. The opinion was that slugs of RDF entered the furnace and would undergo combustion, causing localized positive pressure. The static pressure top for furnace draft and induced-draft fan control was located at approximately the same level as the RDF injection assembly.

After July 23, there were an increased number of incidents as reported by the boiler operators where puffs of black smoke leaked out from around the coal spreaders while the furnace draft went positive for a few moments.

On August 2, a weld on the boiler steam line nonreturn valve developed a leak which necessitated a shutdown for repairs. By this time severe plugging of the inlet region to the superheater section had occurred.

Cleanup of the boiler was made. A decision was also reached to begin testing of unit No. 6 while allowing for some necessary maintenance on unit No. 5 to be completed.

The Iowa coal appeared to have an increased number of fines and this allowed the negative furnace pressure or draft to "suck in" these fines and deposit them on the grate directly in front of the spreader assembly. This in turn, resulted in an inability to provide sufficient heat release for steam generation and subsequent dropping of load. This occurred on July 24, 1976, when at 100% load, a test abort resulted.

During testing of unit No. 5, it appeared that at 100% steam load, insufficient combustion air was supplied through the grate while the induced-draft fan was at its full-open control position. This was attributed to the large amount of air injected by the RDF pneumatic transport air. Measurements of the A and D transport lines indicated approximately 1.9 m^3/sec of air flow were used to inject the RDF.

When unit No. 5 was shut down for cleaning and for repair of the non-return steam valve weld leak, testing was then performed on unit No. 6. Earlier experience obtained from firing unit No. 6 in the spring indicated less wall slagging occurred when the boiler carried lower steam loads and more air. Also, Iowa-Wyoming coal was used in the earlier tests.

Based on this past behavior, a mutual decision was reached that unit No. 6 would be tested at 80% steam load using a 50% mix of Iowa-Wyoming coal.

Upon completion of the tests at 80% steam load on unit No. 6, testing was resumed in unit No. 5 on August 24, 1976.

When the analysis of the major elements of the coal, RDF, grate and collector ash were completed; slagging and fouling indices were calculated for comparative purposes. A high sodium content appears in the RDF which results in a high fouling index. This is discussed later in the report.

The indication of high excess air flow rates by ORSAT flue gas measurements seem substantiated by the boiler operator's comments that the induced draft fans were running wide open especially at the higher steam loads. When testing unit No. 6, this effect was noticed immediately when logging the forced draft and induced draft fan drive motor amperes as indicated on the control panel. Fan motor average amperes for unit No. 6 are shown in Table E-1. No instrumentation for this effect was available on unit No. 5.

Calculated volume flow rates for flue gas and combustion air based on flue gas measurements are shown in Table E-2. Comparison of the actual flow rates at different loads with the original design flow rates (see Appendix A) shows the actual rates are larger.

Several procedures to reduce superheater plugging on unit No. 5 have been attempted. The Appollo Chemical Corporation was contacted by plant personnel and this company injected their additives into the RDF transport lines. The objective was to try to soften the accumulated slag on the superheater tubes so that the material would drip off. This proved unsuccessful.

In January 1977, a new procedure was incorporated by Ames power plant personnel. At approximately 4 PM every afternoon, RDF firing is stopped and the boiler load is measured to 34,000 kg/hr (75,000 lb/hr) for about 2 hr, then, normal firing at about 27,200 kg/hr (60,000 lb/hr) of steam generation is resumed. The consensus of operating personnel is that the slag buildup is reduced with some dripping down or fall off of the slag material taking place. In addition, long travel soot blowers are being installed in the superheater region of unit No. 5. Unit No. 6 does contain soot blowers in the superheater region.

SECTION 7

BOILER PERFORMANCE RESULTS

EXCESS AIR

Figures 12 and 13 show the excess air for the tests as a function of percent RDF heat input and boiler steam load. The firing of the two stoker units was manually controlled by the boiler operator until the fire and boiler operation appeared to be "right," based on the operators' experience. The flue gas was sampled, and the boiler operators were informed of the CO_2 and O_2 content so they would have an indication of how much excess air they were running. At the higher steam loads, the amount of air which could be supplied was limited by the capacity of the induced draft fan. This problem was especially acute when RDF was being burned because of the additional air supplied by the RDF transport lines. Air flow through RDF transport line A is 904 liters/sec and line D is 768 liters/sec; these values are based on two separate sets of flow measurements with air alone.

Due to the variability in the coal (some of the Iowa coal had a large amount of fines) and the boiler operators, there was considerable variability in the excess air achieved. There are, however, some trends which are worth noting because of the effect that they have on the boiler performance parameters. Figures 12 and 13 show that generally the excess air increased when any refuse was burned. This is due to the extra air which was being supplied by the pneumatic RDF feeders. The boiler operators were not fully aware of the amount of air this was contributing and hence, tended to leave the forced draft fan settings about the same as when firing coal alone. In a sense, this was to be expected since the additional air coming through the pneumatic RDF feeders did not come through the grate where the fuel was burning and thus, did not contribute to the primary combustion air. The average increase in excess air (for all loads on boiler unit No. 5) was 8.0% for 20% RDF and 13.7% for 50% RDF as compared to coal alone (0% RDF). Boiler unit No. 6 excess air increased approximately 14% for RDF compared to coal alone.

Figure 13 indicates that the amount of excess air for unit No. 5 decreased substantially as percent steam load increased. This was true of all levels of RDF heat input. The excess air ranged from an average of 130% at 60% steam load, 109% at 80% load, to 69% at 95% steam load. Boiler unit No. 6 averaged 86%

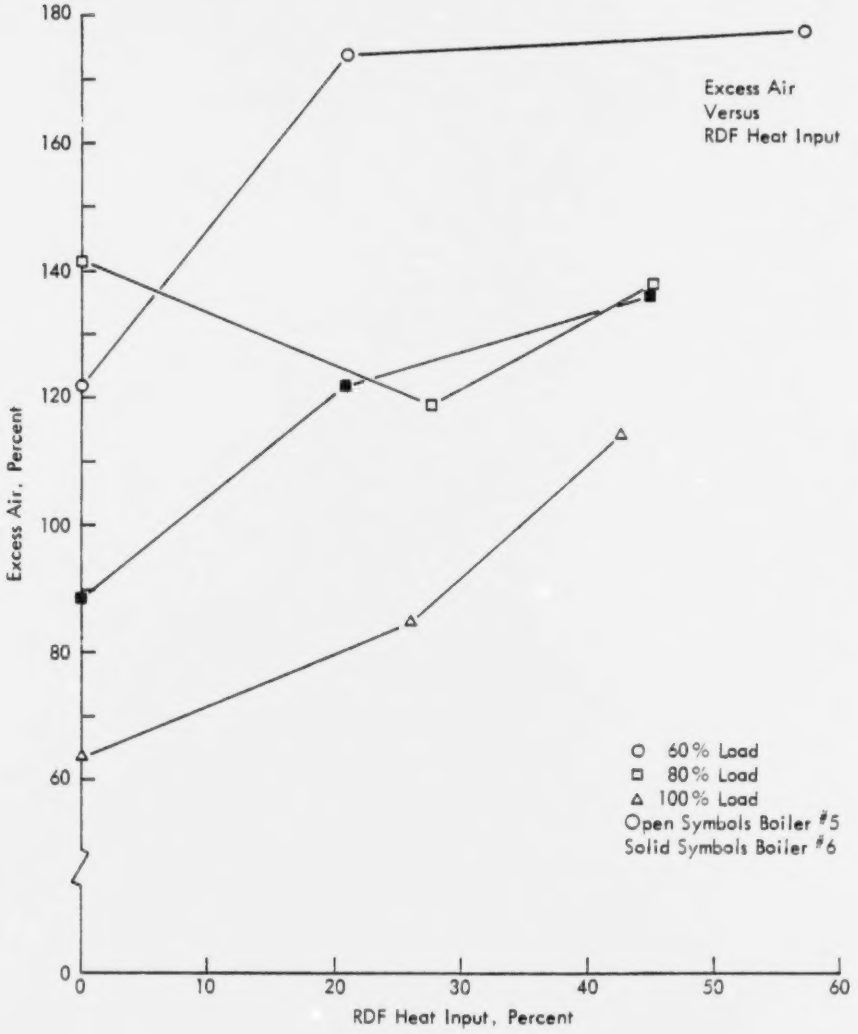

Figure 12. Excess air of boiler units Nos. 5 and 6 as a function of RDF heat input.

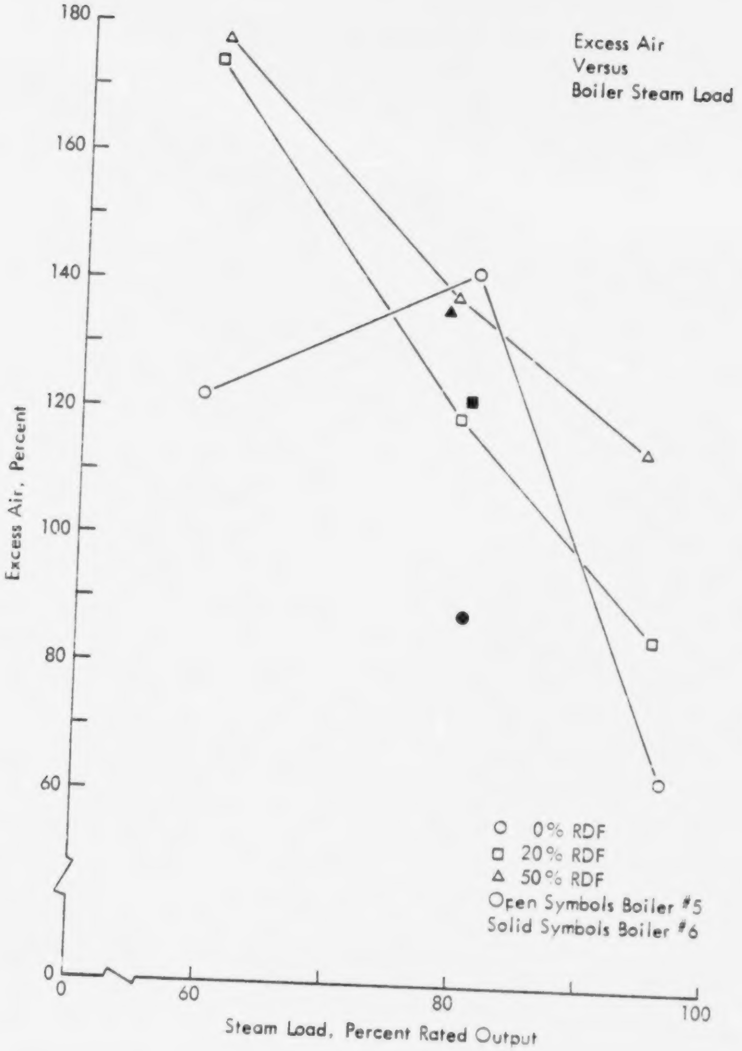

Figure 13. Excess air of boiler units Nos. 5 and 6 as a function of boiler steam load.

excess air at 80% load, ranging from 70% for coal alone, 96% for 20% RDF and 92% for 50% RDF heat input. In summary, excess air increased significantly when RDF was burned due to air injected by the pneumatic RDF feeders, but excess air decreased markedly as steam load increased due to the capacity limitations of the induced draft fan.

BOILER EFFICIENCY

The thermal efficiencies of the boiler units were determined by both the direct and indirect methods according to the following relationships.

$$\eta \text{ direct} = \frac{\text{Q Steam}}{\text{Heat input}} = \frac{\text{Steam flow rate } [\text{kg/hr}] \times [h_{out} - h_{in}]\,[\text{kJ/kg}]}{\text{Fuel firing rate } [\text{kg/hr}] \times \text{HHV}_{fuel}\,[\text{kJ/kg}]}$$

and

$$\eta \text{ indirect} = 1 - \frac{\text{Q loss}}{\text{Heat input}}$$

where $Q_{loss} = Q_{loss}$ (dry flue gas) $+ Q_{loss}$ (combustible in ash)

$+ Q_{loss}$ (water in flue gas) $+ Q_{loss}$ radiation*

Figures 14 and 15 show the boiler efficiency calculated by the direct method for varying percent RDF heat input and percent load, while Figures 16 and 17 show boiler efficiency calculated by the indirect method. The agreement between the values obtained by the two methods is less consistent than one might hope. This could be due to uncertainties in the determination of coal and RDF flow rates, excess air, and heating values of coal and RDF.

The indirect boiler efficiency versus percent RDF heat input (Figure 16) indicates that there is a decrease in efficiency as RDF heat input increases. The direct method, Figure 14, verifies this except in the case of boiler unit No. 5 at 60 and 100% load. This decrease is most likely due to the increase in excess air when refuse was burned (approximately 1,900 liters/sec of air injection by pneumatic RDF feeders). The increase in excess air (see Figure 12) ranged from 10 to 30% when RDF was fired compared to coal alone. This would be sufficient to account for the observed decrease in boiler efficiency. One should not automatically conclude that it would be possible to restrict the air supplied under the grate by the forced draft fan and thereby hold excess air constant. The air would not come through the grate as primary air and thus would probably cause an increase in combustible lost in the ash. In addition there might be considerable problems with slagging and fouling if the excess air were limited. An alternate approach would be to separate the transport air from the pneumatic RDF feed lines by cyclone separation and inject the RDF by gravity or a screw conveyor.

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* Estimated from ASME Power Test Code.

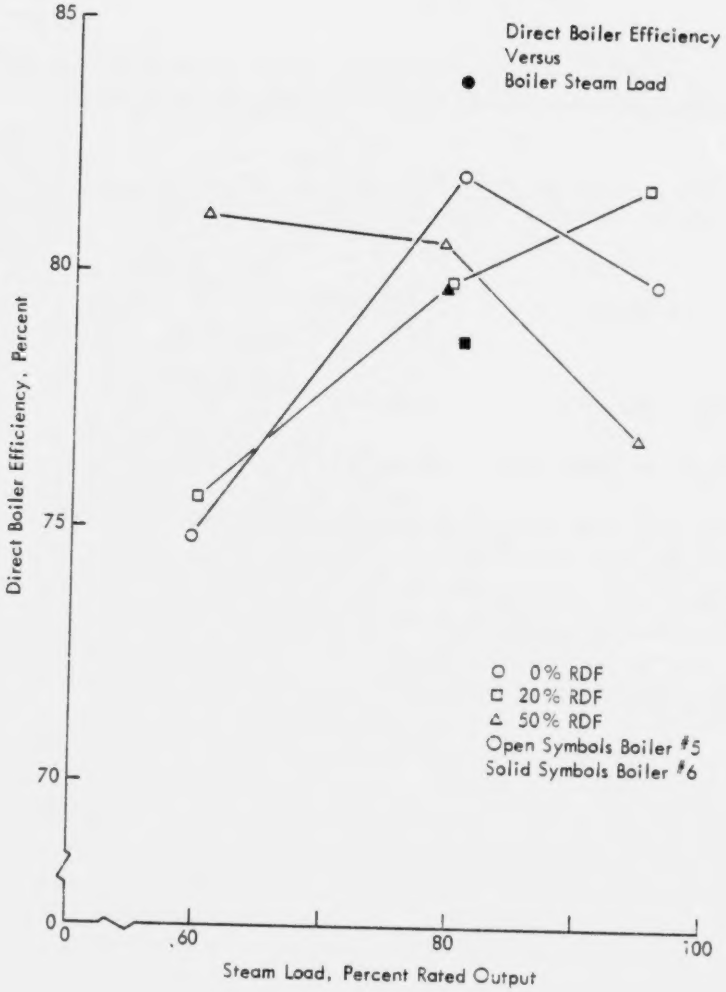


Figure 14. Direct boiler efficiency of boiler units Nos. 5 and 6 as a function of boiler steam load.

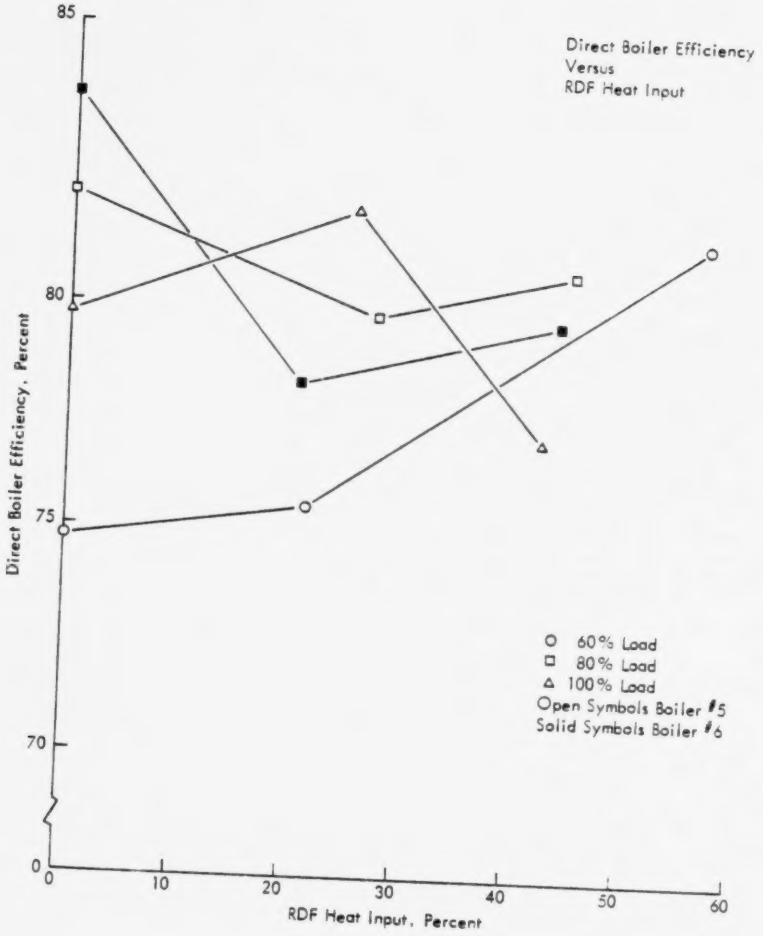


Figure 15. Direct boiler efficiency of boiler units Nos. 5 and 6 as a function of RDF heat input.

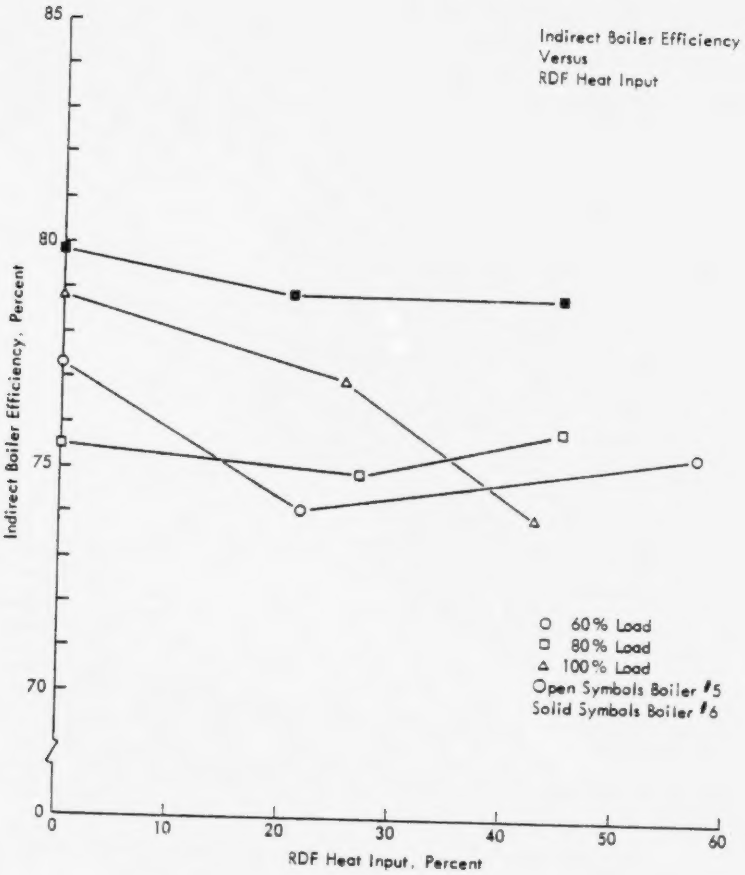


Figure 16. Indirect boiler efficiency of boiler units Nos. 5 and 6 as a function of RDF heat input.

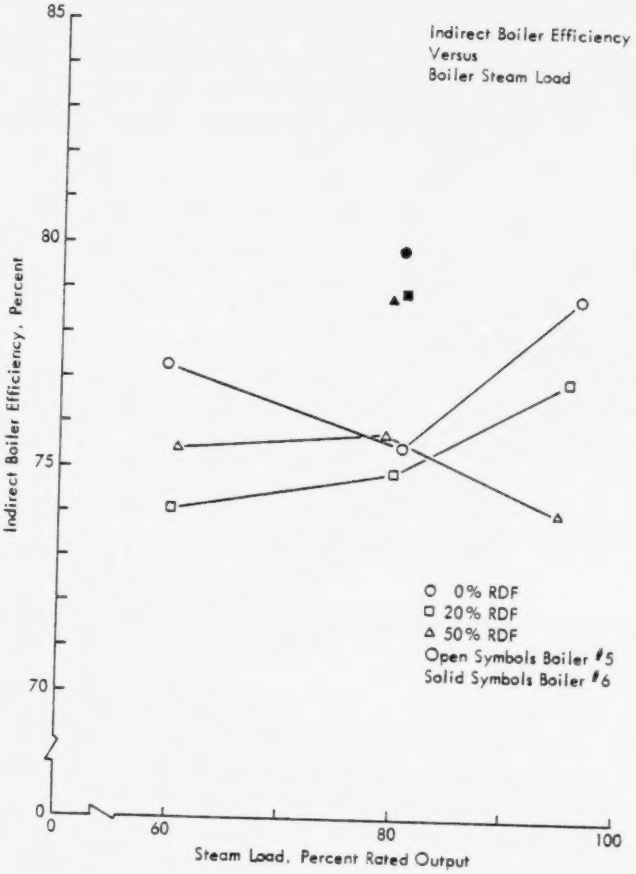


Figure 17. Indirect boiler efficiency of boiler units Nos. 5 and 6 as a function of boiler steam load.

Figures 18 and 19 show the average of the direct and indirect method boiler efficiency versus percent RDF heat input and percent steam load. The same general trends previously mentioned are noted.

The results indicate that there was no significant change in the percent of the heat input leaving as combustible in the ash which tends to support the hypothesis that the burning of RDF did not have a direct detrimental effect on boiler efficiency.

Another factor which possibly affected the boiler efficiency was the slag and fouling deposit buildup on the boiler tubes due to the burning of RDF. Since the various levels of steam load and percent RDF heat input were scheduled in a random fashion, there is no way to quantify or correlate the effect of slag buildup on thermal efficiency. Thus, it must be classed as an uncontrolled and unmeasured variable.

In summary, the only direct effect of burning RDF on the measured indirect boiler efficiency was a 1-1/2% decrease due to the increased moisture content of the RDF (50% by heat input).

PARTICULATE COLLECTOR EFFICIENCY

Figures 20 and 21 portray the effect of percent RDF heat input and percent load on the particulate collector efficiency. These efficiencies were measured by determining the total particulate loading before and after the multiclone particulate collectors with an EPA Method 5 train and calculating the collection efficiency as follows:

$$\eta_{\text{collector}} = 1 - \frac{\text{mass of particulate out of the collector}}{\text{mass of particulate into the collector}}$$

Figure 20 shows that there was an increase in collector efficiency as the percent RDF heat input increased for unit No. 5 at 80 and 100% load. For 60% load, the collection efficiency decreased slightly when 60% RDF was burned. Particulate collection efficiency for boiler unit No. 6 did not vary significantly with percent RDF. The tendency for the efficiency of the collector to increase with percent RDF is plausible when one recognizes that the particles in the flue gas which come from the RDF are larger in size than those from coal alone. Since the multiclones are more efficient at separating larger particles, the efficiency should increase as percent RDF increases.

Figure 21 indicates that the collection efficiency was greatest at 80% load for all levels of RDF. Values of efficiency for boiler unit No. 5 average 71.2, 87.2, and 80.0% at 60, 80, and 100% load, respectively.

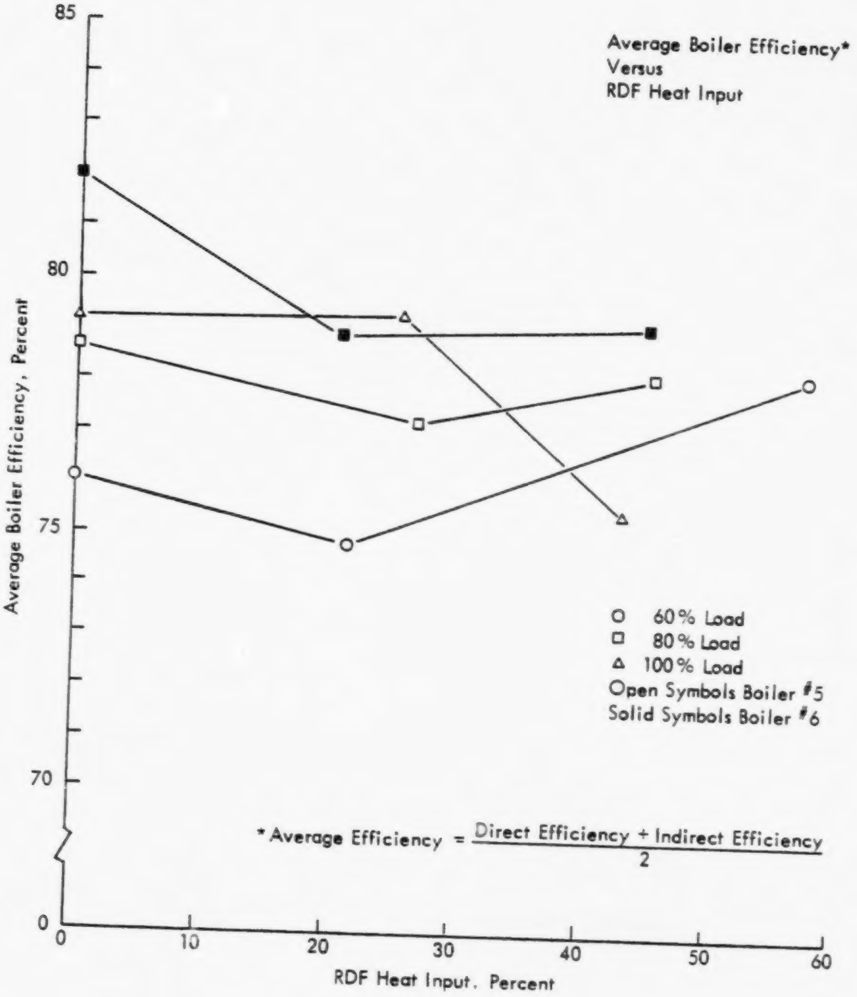


Figure 18. Average boiler efficiency of boiler units Nos. 5 and 6 as a function of RDF heat input.

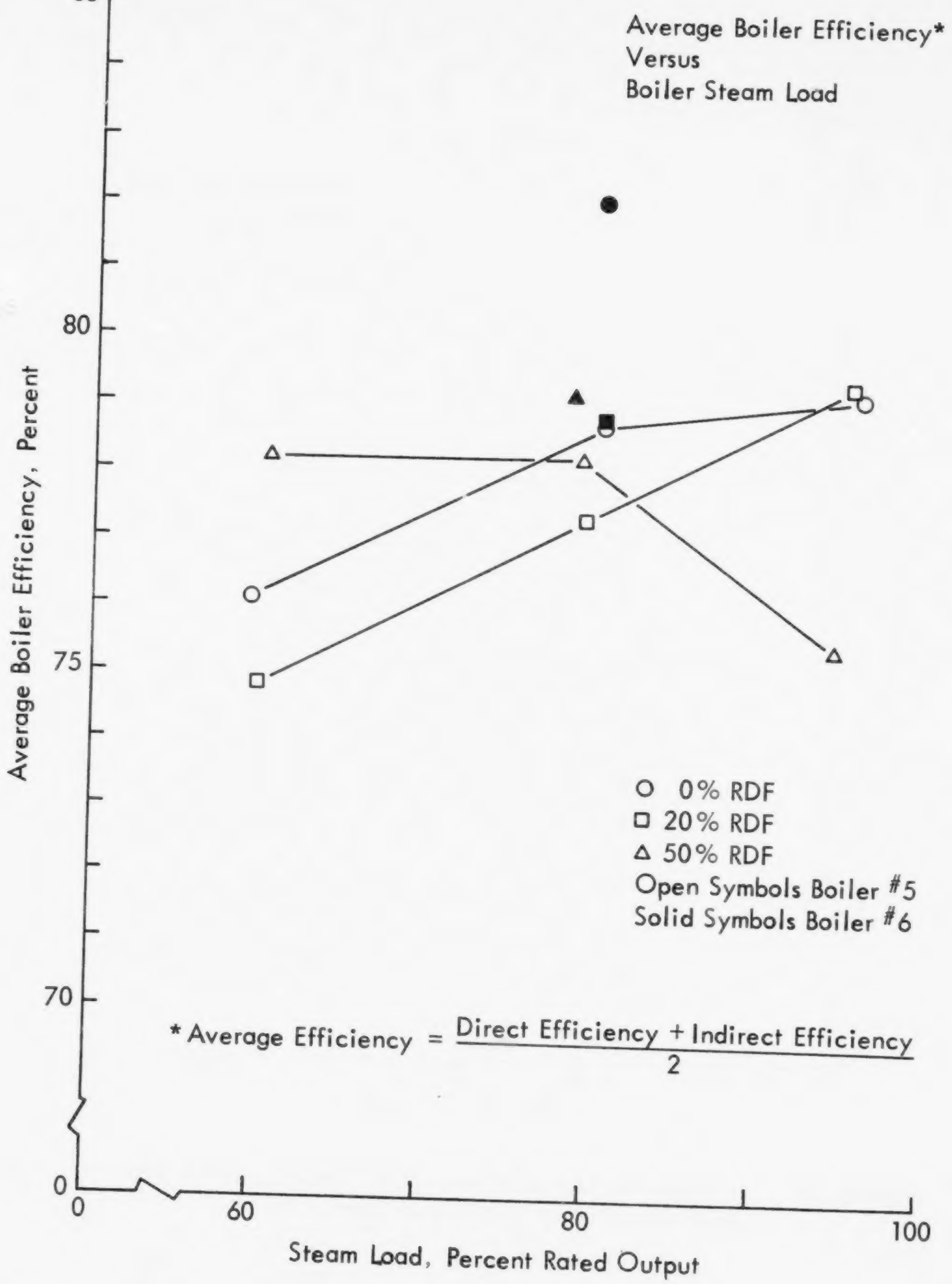


Figure 19. Average boiler efficiency of boiler units Nos. 5 and 6 as a function of boiler steam load.

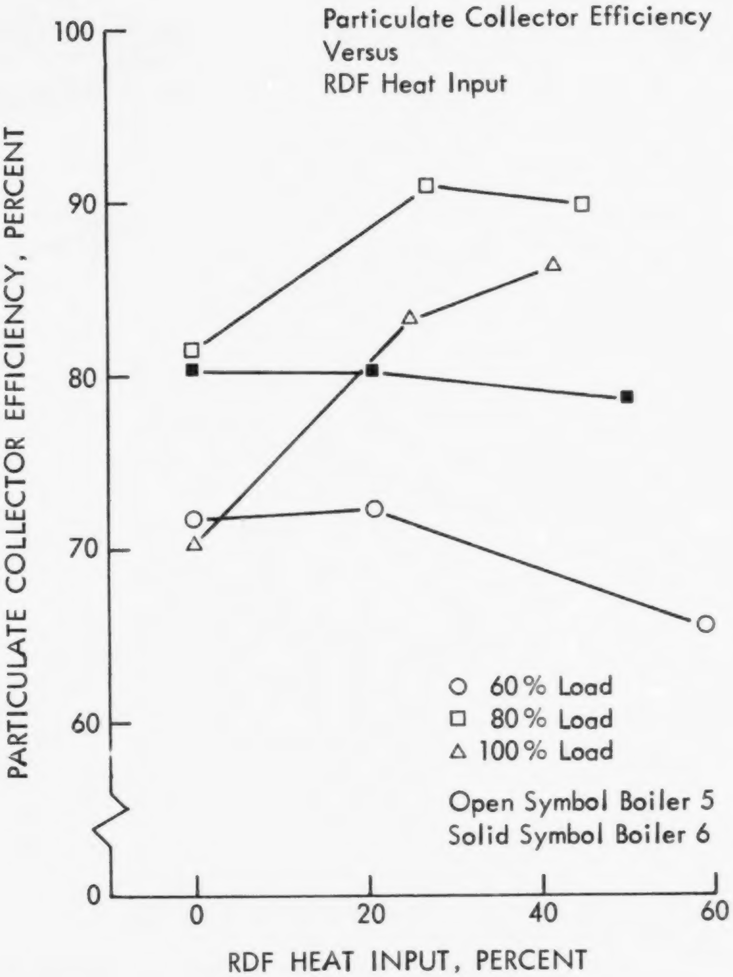


Figure 20. Particulate collector efficiency of boiler units Nos. 5 and 6 as a function of RDF heat input.

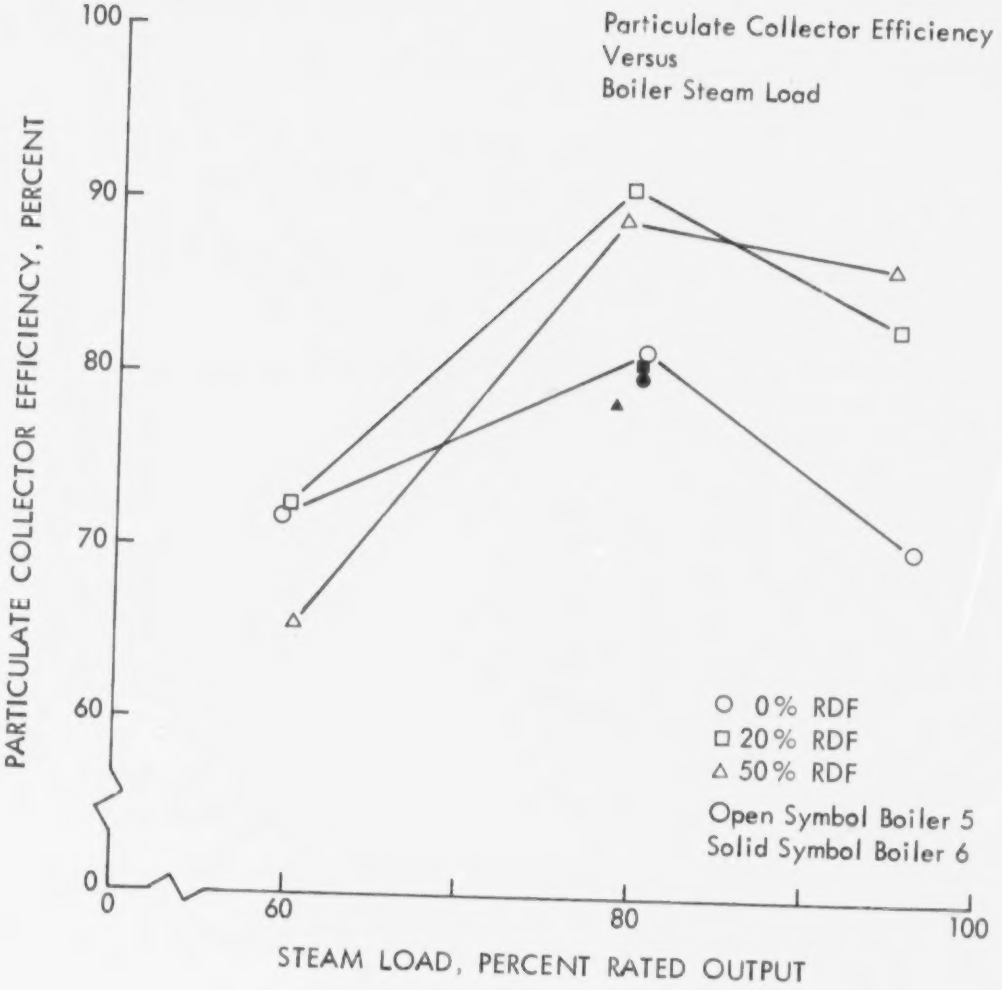


Figure 21. Particulate collector efficiency of boiler units Nos. 5 and 6 as a function of boiler steam load.

Boiler unit No. 6 collector efficiency averaged 79.7% at 80% load. The overall collector efficiency for all runs was 79.5% for boiler unit No. 5.

FUEL UTILIZATION

Figures 22 and 23 relate the percent of the total fuel heat input lost due to combustible (primarily carbon) loss in the ash as a function of percent RDF heat input and percent boiler steam load. These results are calculated by determining the amount of ash by using an ash balance and the fuel and ash ultimate analysis. Figures 24 and 25 show the same information except the ash was determined by weighing the ash accumulated over the entire duration of the run. Although there are some differences in the losses calculated by the two methods, the trends as percent RDF and percent load varied are similar. The results show that there was no significant change in the percent of total heat input lost as the percent RDF heat varied from 0 to 50%. The average loss for unit No. 5 was approximately 4.1% using measured ash flow rates and 5.6% for calculated ash flow rates. The heat loss to the ash for boiler unit No. 6 was only 2.1% (average of calculated and weighed ash method). There was a slight increase in the heat loss in the ash as percent load increased. This can be explained by the fact that excess air decreased markedly with load (discussed elsewhere), and that the grate loading (fire bed depth) increased resulting in some incomplete burning.

Figures 26, 27, 28, and 29 depict the percentage of the RDF heat input which was lost as combustibles in the ash. The combustible loss in the ash attributable to RDF was calculated as follows: the amount of combustibles from the coal is assumed to be the same when burning a mixture of coal and RDF as when burning coal alone (at a fixed level of load).

For coal alone:

$$\frac{\text{\% Coal Heat Value in Ash}}{\text{Heat Input from Coal}} = \frac{\Sigma M_{ash} \times \text{Heat Value}_{ash}}{M_{coal} \times \text{Heat Value}_{coal}} \times 100$$

For coal and RDF:

$$\frac{\text{\% RDF Heat Value in Ash}}{\text{Heat Input From RDF}} =$$

$$\frac{\Sigma M_{ash} \times \text{Heat Value}_{ash} - M_{coal} \times \text{Heat Value}_{coal} \times \frac{\text{\% Coal Loss to Ash}}{100}}{M_{RDF} \times \text{Heat Value}_{RDF}}$$

where M = mass (kg)

A question can be raised regarding the assumption that the coal combustible loss remains the same when firing coal + RDF. In fact, the coal loss may decrease with the presence of RDF due to the higher excess air flow rates

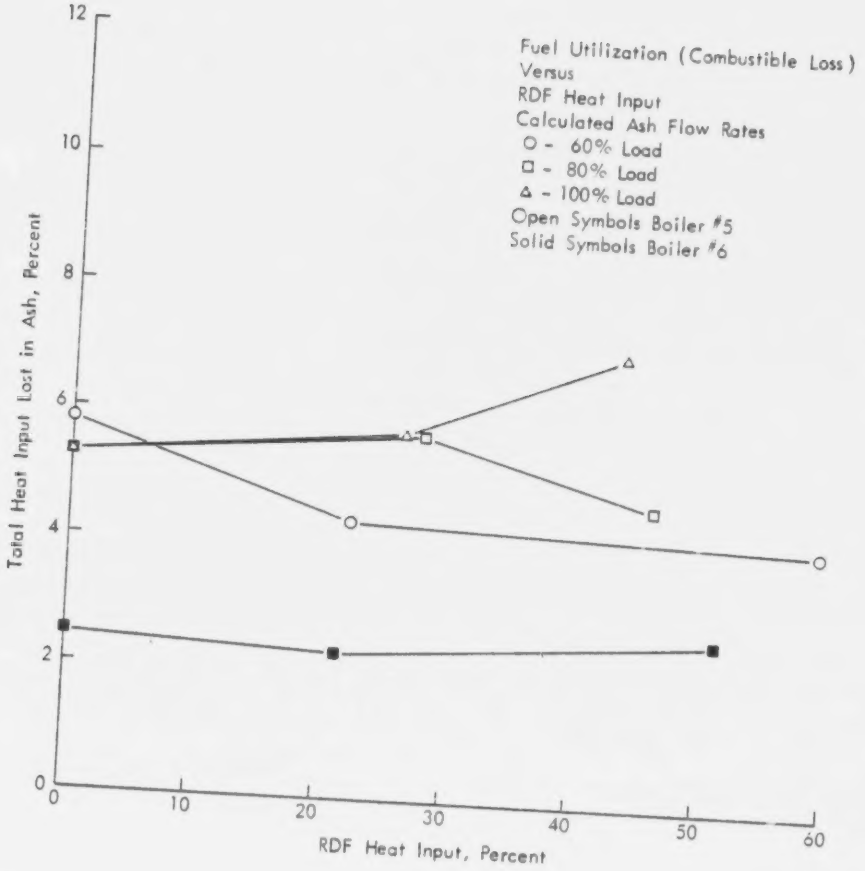


Figure 22. Fuel utilization of boiler units Nos. 5 and 6 as a function of RDF heat input, as determined from calculated ash flow rates.

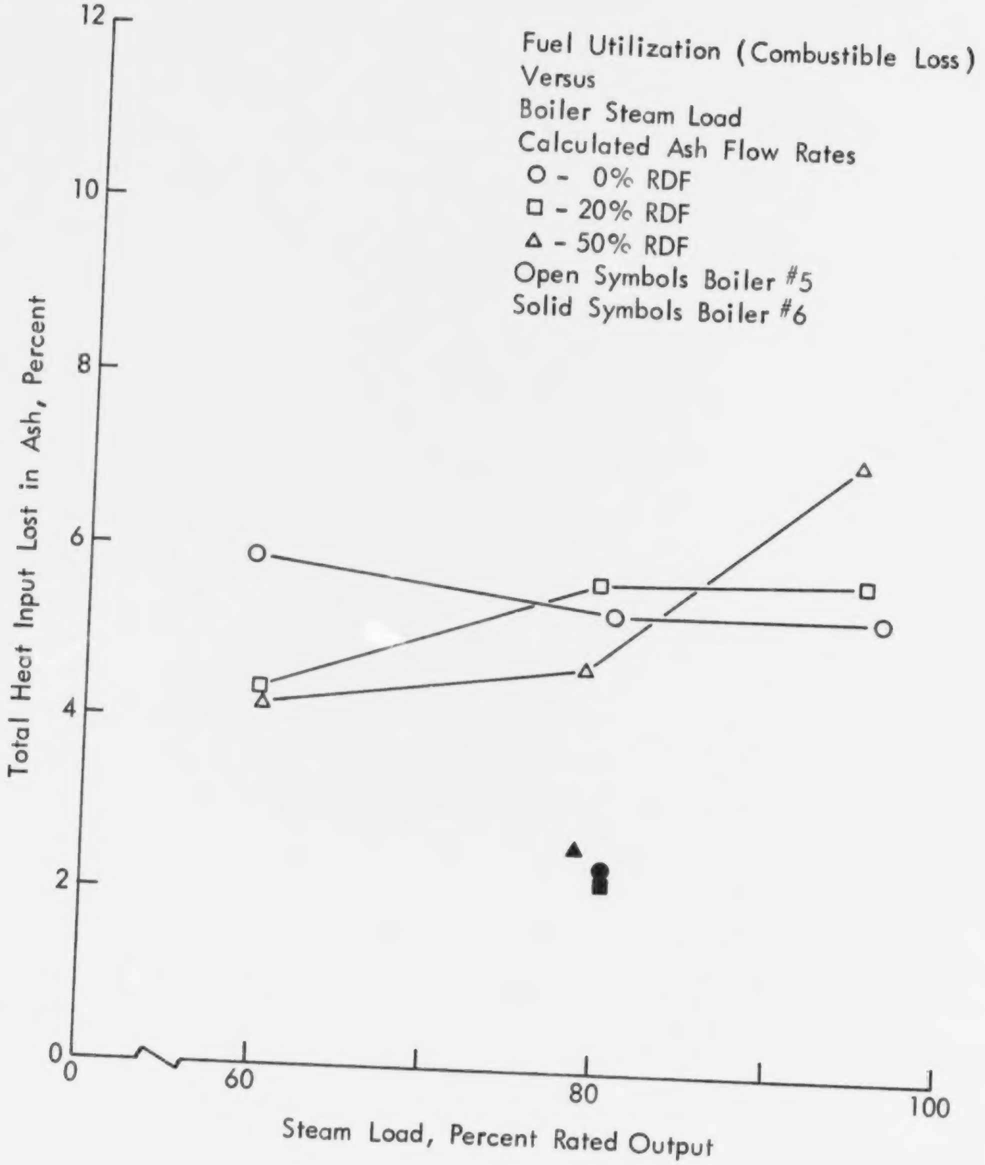


Figure 23. Fuel utilization of boiler units Nos. 5 and 6 as a function of boiler steam load, as determined from calculated ash flow rates.

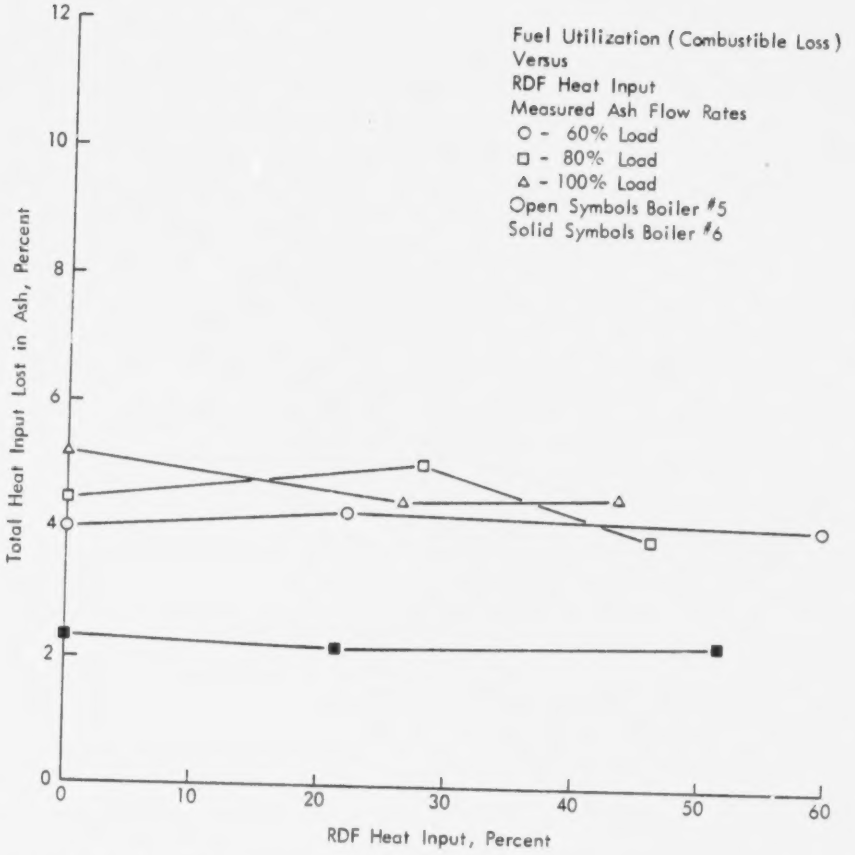


Figure 24. Fuel utilization of boiler units Nos. 5 and 6 as a function of RDF heat input, as determined from measured ash flow rates.

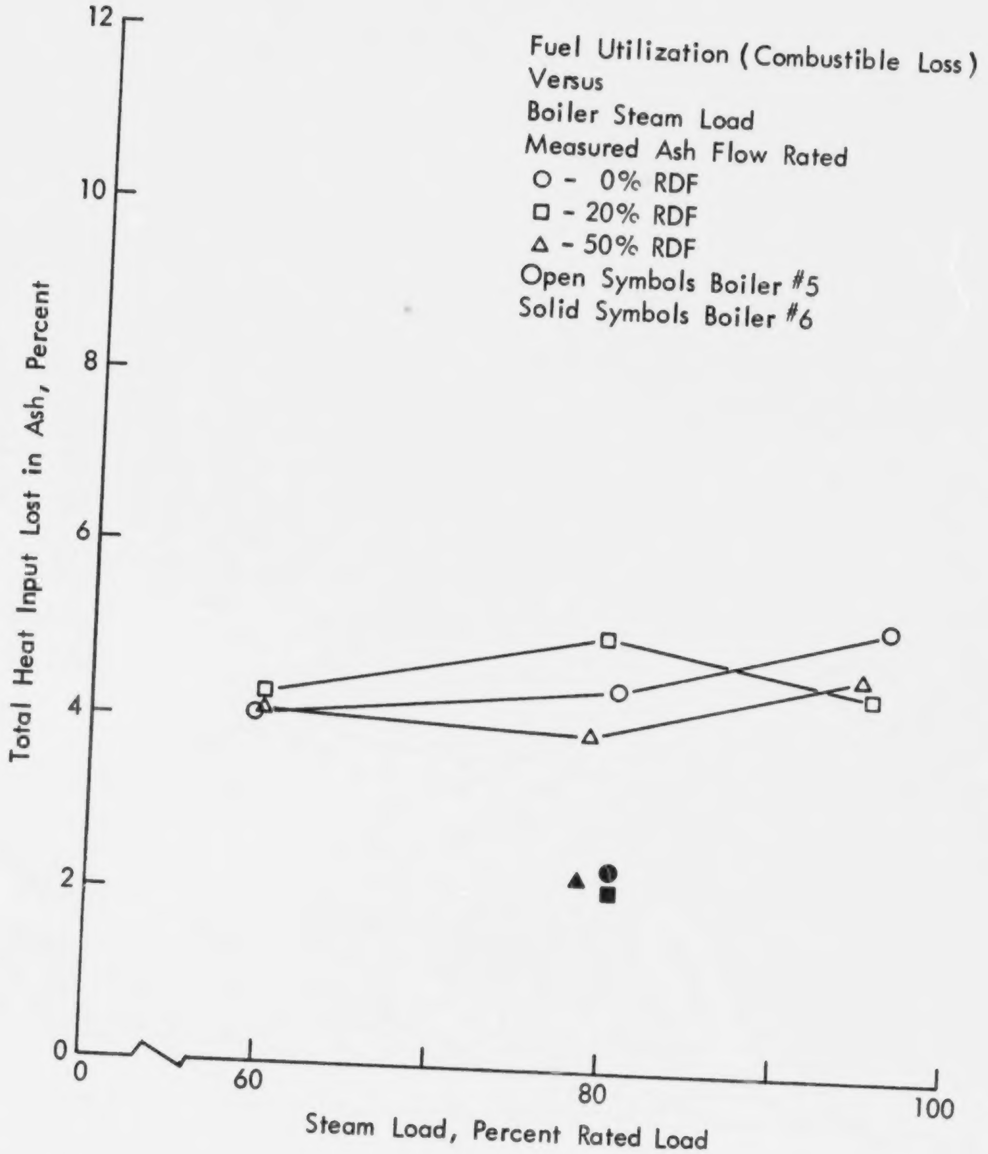


Figure 25. Fuel utilization of boiler units Nos. 5 and 6 as a function of boiler steam load, as determined from measured ash flow rates.

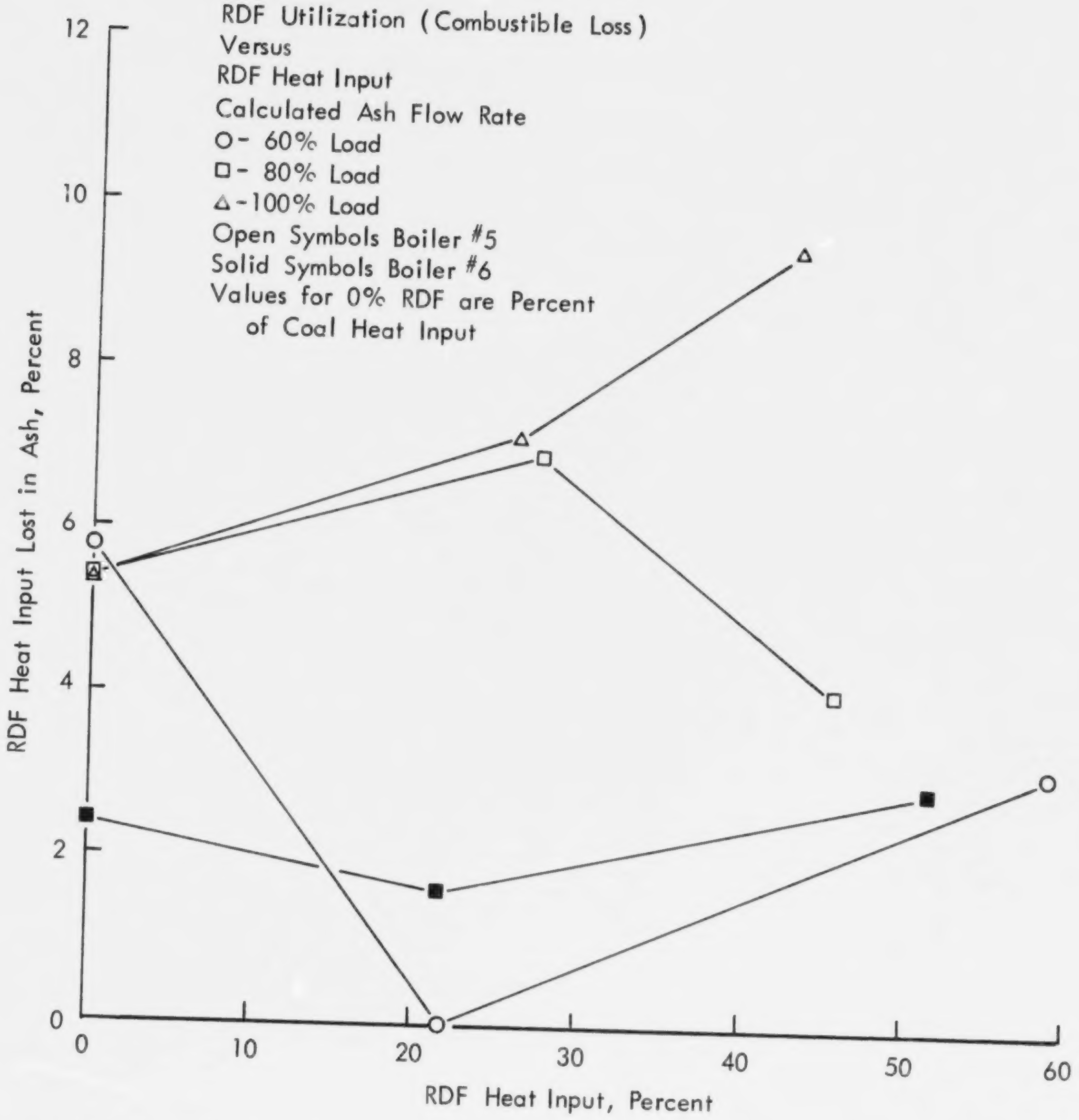


Figure 26. RDF utilization of boiler units Nos. 5 and 6 as a function of RDF heat input, as determined from calculated ash flow rates.

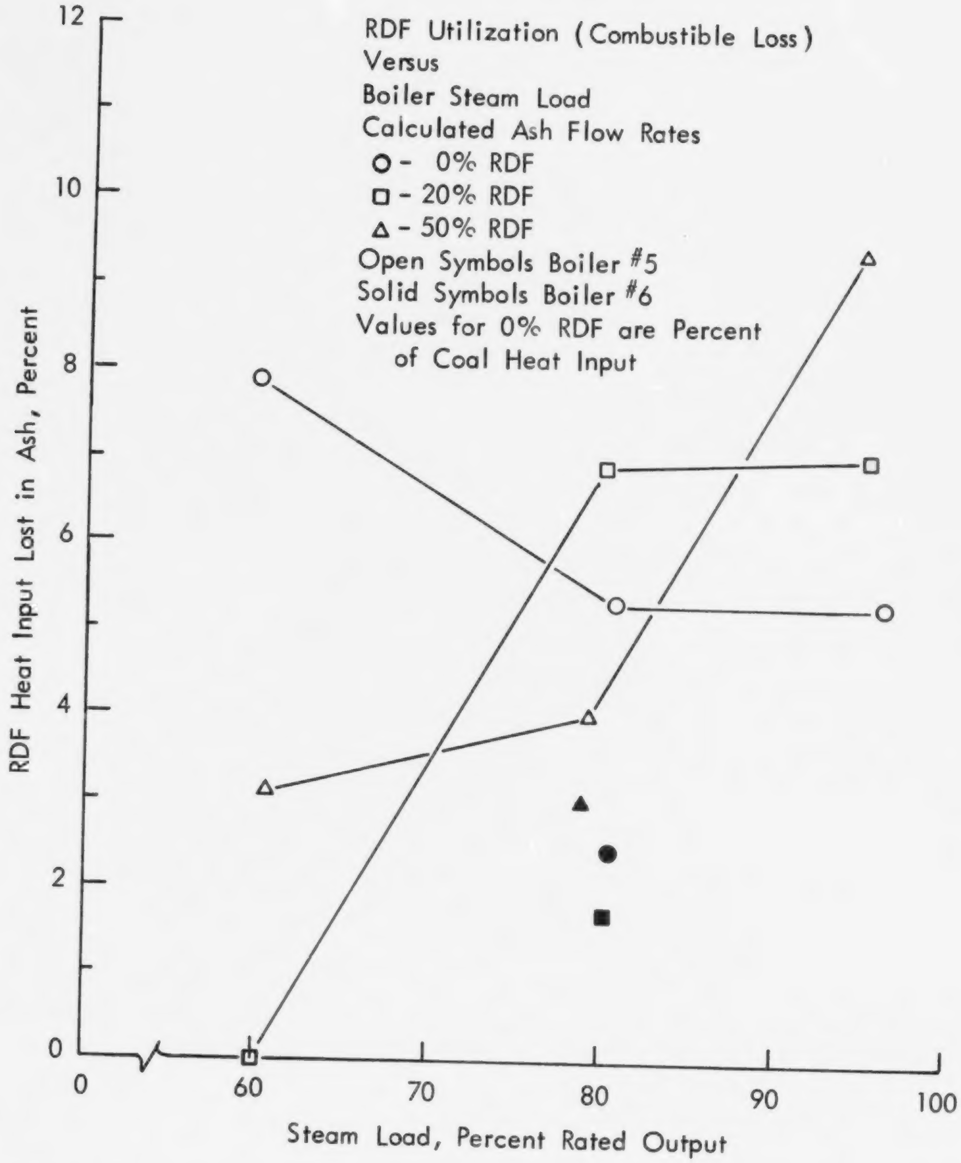


Figure 27. RDF utilization of boiler units Nos. 5 and 6 as a function of boiler steam load, as determined from calculated ash flow rates.

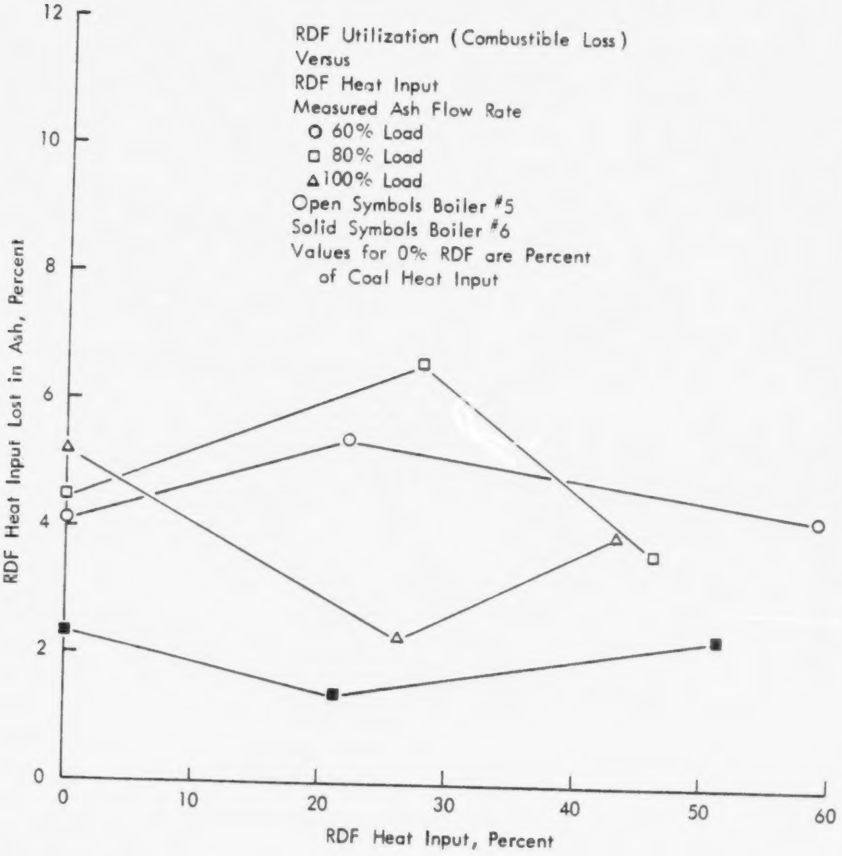


Figure 28. RDF utilization of boiler units Nos. 5 and 6 as a function of RDF heat input, as determined from measured ash flow rates.

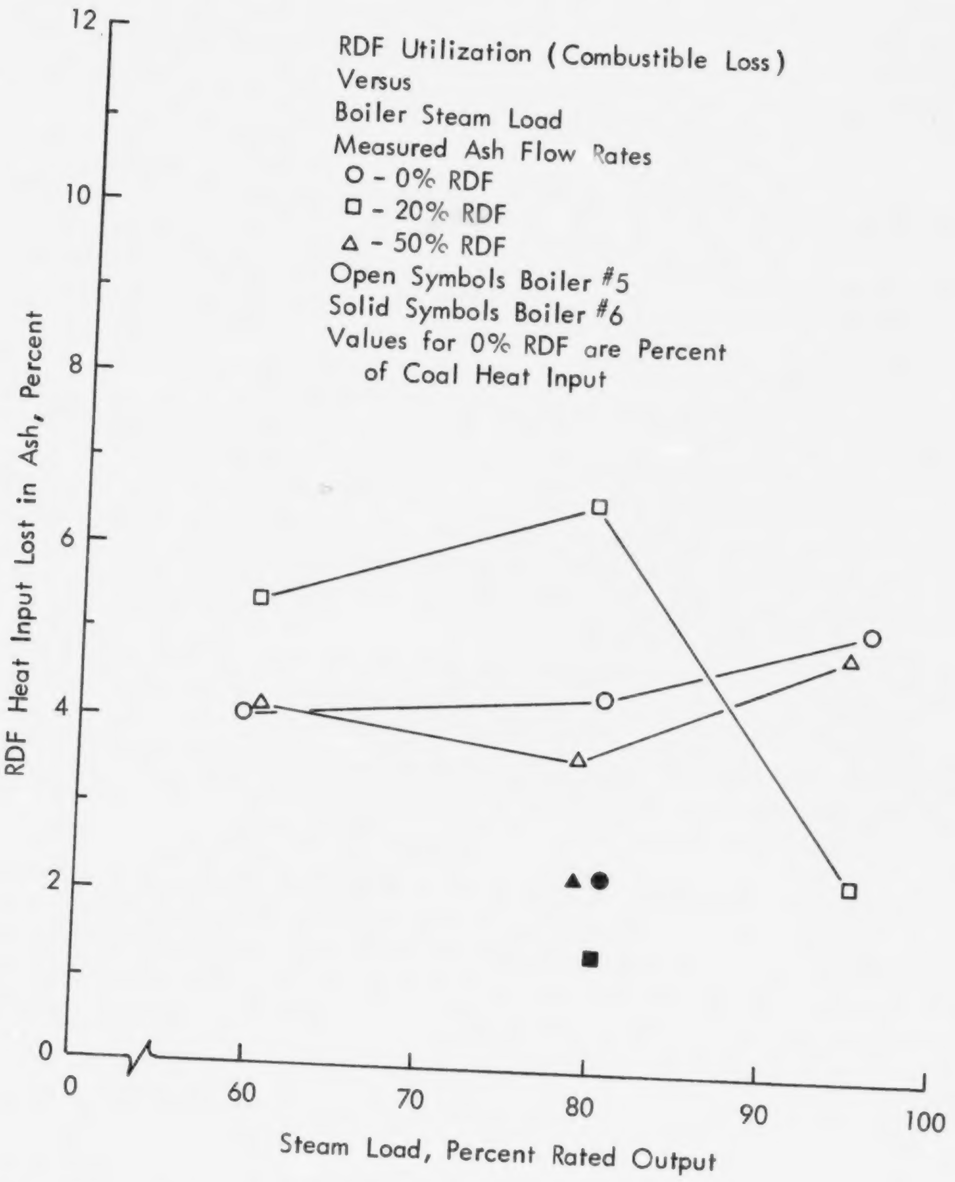


Figure 29. RDF utilization of boiler units Nos. 5 and 6 as a function of boiler steam load, as determined from measured ash flow rates.

relative to coal flow. This would tend to make the coal heating value loss less and tend to increase the apparent loss from the RDF. It is quite likely that the inconsistent behavior of RDF utilization values were due to the above assumption. It is significant to note that the total fuel combustible loss remained essentially constant with increased RDF burning rates. In summary, RDF was successfully burned with a utilization efficiency of approximately 95%. There was no decrease in the utilization efficiency of RDF as compared to coal alone at a given boiler steam load.

CHEMICAL ANALYSIS OF FUEL, GRATE ASH, AND COLLECTOR ASH

Laboratory analysis of coal, RDF, grate ash, and collector ash by the X-ray fluorescence (XRF) method at the Ames Laboratory/ERDA, provided a list of trace elements. Included in the trace elements were aluminum (Al), silicon (Si), titanium (Ti), potassium (K), and iron (Fe). The method would allow for detection of sodium (Na), magnesium (Mg), and phosphorus (P). All of these specified elements expressed as oxides constitute what is known as the major chemical analysis of the mineral ash of coal. This analysis was also extended to RDF. In addition, when the grate ash and collector ash were analyzed in the laboratory, similar chemical analyses were determined. These elements, in oxide form, were expressed as weight percent of the "ashed" material. These major elements form a basis for calculation of slagging and fouling indices.

The elements analyzed by the Ames Laboratory were converted to the oxide form. Sodium, magnesium and phosphorous analyses were determined by a commercial laboratory. The sum of these oxide weights, when expressed as percent weight of the fuel, grate ash, or collector ash should be equal to the mineral ash weight percent as determined in the normal "ultimate analysis" laboratory procedure.

It was indicated that the reported analysis of Al, Si, Ti, K, and Fe as analyzed by XRF was sensitive to detection limits. In order to account for the difference in ash content weights calculated from the sum of the chemical oxides and the ash weight percent reported in the ultimate analysis, the ratio of the latter to the former was used to correct the oxides calculated from the trace element analysis.

The corrected major chemical analyses expressed in the oxide form for coal, RDF, grate ash, and collector ash are shown in Tables D-3 and D-4. It should be noted that higher amounts of both silica (SiO_2) and sodium oxide (Na_2O) are present in the RDF. Visual observations of RDF while being sampled indicated high-ground glass interspersed among the material.

SLAGGING-FOULING INDICES

Potential slagging-fouling problems are evaluated by relationships that involve the major chemical elements of mineral ash expressed in oxide form. These are:

Slagging Index = (Base/Acid) x (% Sulfur on Dry Coal Basis)
Fouling Index = (Base/Acid) x (% Na_2O)
where

$$\text{Base/Acid} = \frac{Na_2O + K_2O + Fe_2O_3 + CaO + MgO}{SiO_2 + Al_2O + TiO_2}$$

Although previously developed for coal, these indices were calculated for coal, RDF, grate ash, and collector ash. These values are shown in Table D-5.

Potential difficulty of slagging in the furnace wall section or fouling in the boiler convection passes is based on the criteria as follows:

Slagging Type	Slagging Index
Low	less than 0.6
Medium	0.6 - 2.0
High	2.0 - 2.6
Severe	greater than 2.6

Fouling Type	Fouling Index
Low	less than 0.2
Medium	0.2 - 0.5
High	0.5 - 1.0
Severe	greater than 1.0

The most significant influence is the higher sodium content of the RDF and its effect on the fouling index. Severe buildup and ultimate plugging in the slag-screen/superheater section of unit No. 5 resulted in the shutdown and cleanup of the boiler. Upon completion of the testing phase on September 1, 1976, this unit was switched from using 100% Iowa coal to a 50% mixture each of Iowa and Wyoming coal.

Unit No. 6 has not experienced the severe plugging and this may be due to the geometry of tube arrangement at the superheater inlet region. In addition, furnace exit temperatures are not available so this behavior is still being investigated.

The application of slagging index may not be appropriate due to the potential presence of clear, brown or green ground glass by itself in the injected RDF. The initial fusion temperatures of clear glass (800°C), brown and green glass (900°C) when not mixed may promote the presence of soft viscous or sticky material after furnace injection and melting. With nonoperation of the distributor air nozzles, slag buildup occurs mostly along the front furnace wall and the sidewall areas in the region of the coal spreader and refuse injectors. Slag buildup occurred along the bottom back wall of both units.

In any case, the injection of large amounts of air into the furnace coupled with the slag-covered walls would tend to decrease the heat transfer in the furnace region and raise the furnace exit temperature of the flue gas entering the superheater section. Hence, the fly ash suspended in the flue gas would be softer and tend to form deposits and buildup. Examination of boiler control board gas temperatures for unit No. 5 indicates that flue gas temperatures upon entering and leaving the economizer increased by 10 to 14°C when burning RDF.

ASH FUSION TEMPERATURES

Ash fusion temperatures, as determined by ASTM method 1857, of the coal, RDF, grate ash, and collector ash for each test run are shown in Appendix D.

No specific correlation of behavior has been determined yet, although in general, RDF fusion temperatures were anywhere from 40 to 90°C lower than those for coal. A comparison of the initial fusion temperature, under a reducing atmosphere, for various steam loads is shown in Figures 30 through 33.

ASH FLOW RATES

Measured grate and collector flow rates, expressed as kg of ash per 100 kg of steam flow are shown in Figures 34 through 37. Generally, grate ash and total ash flow rates increased with increases in RDF firing rates.

INTERIM SAMPLING OF RDF (EPA TASK NO. 5)

Initial characterization of RDF was made during the period April 1976, through June 1976. The sampling procedure and results are discussed in great detail in Appendix F.

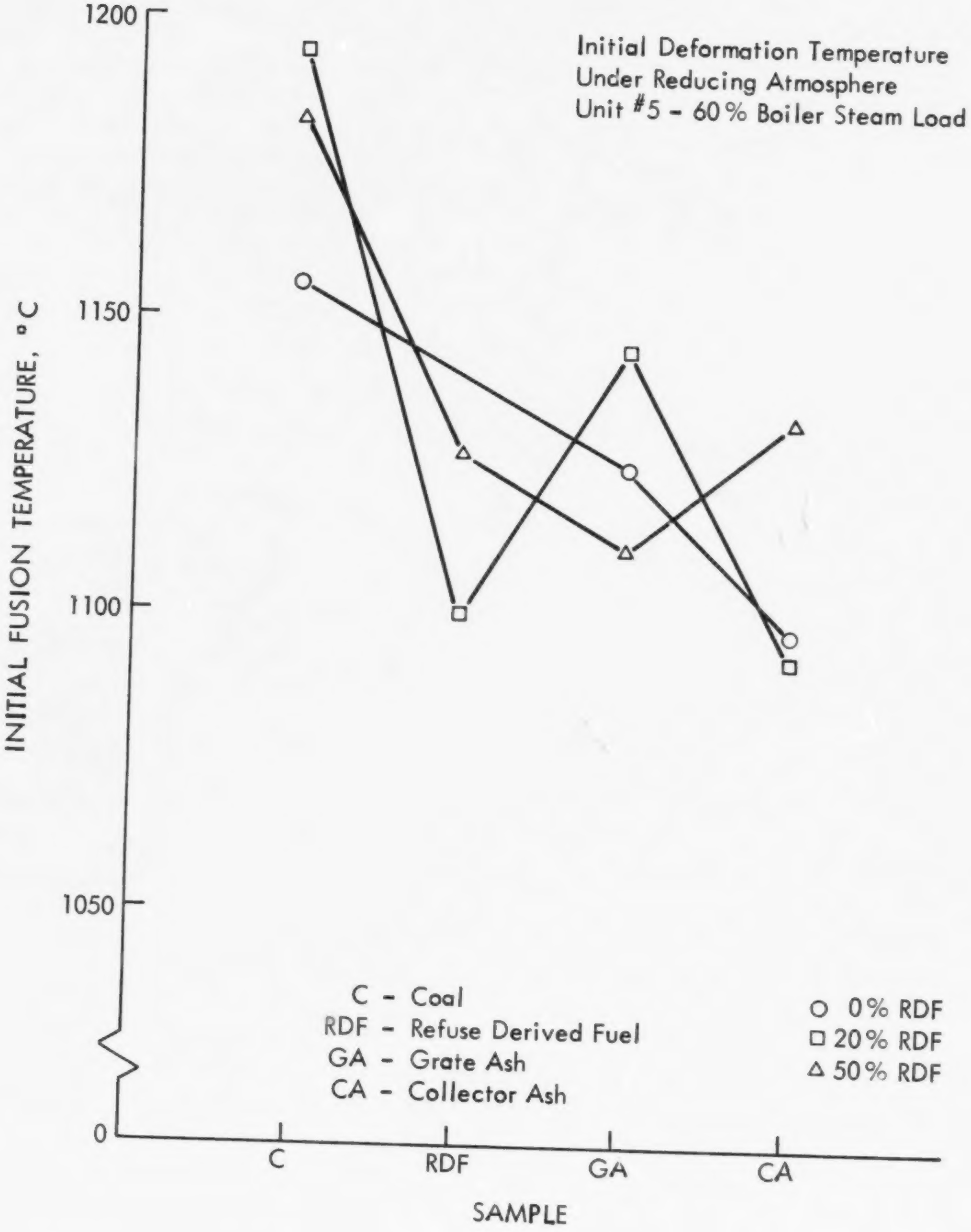


Figure 30. Initial deformation temperature, under reducing atmosphere, of boiler unit No. 5 at 60% boiler steam load.

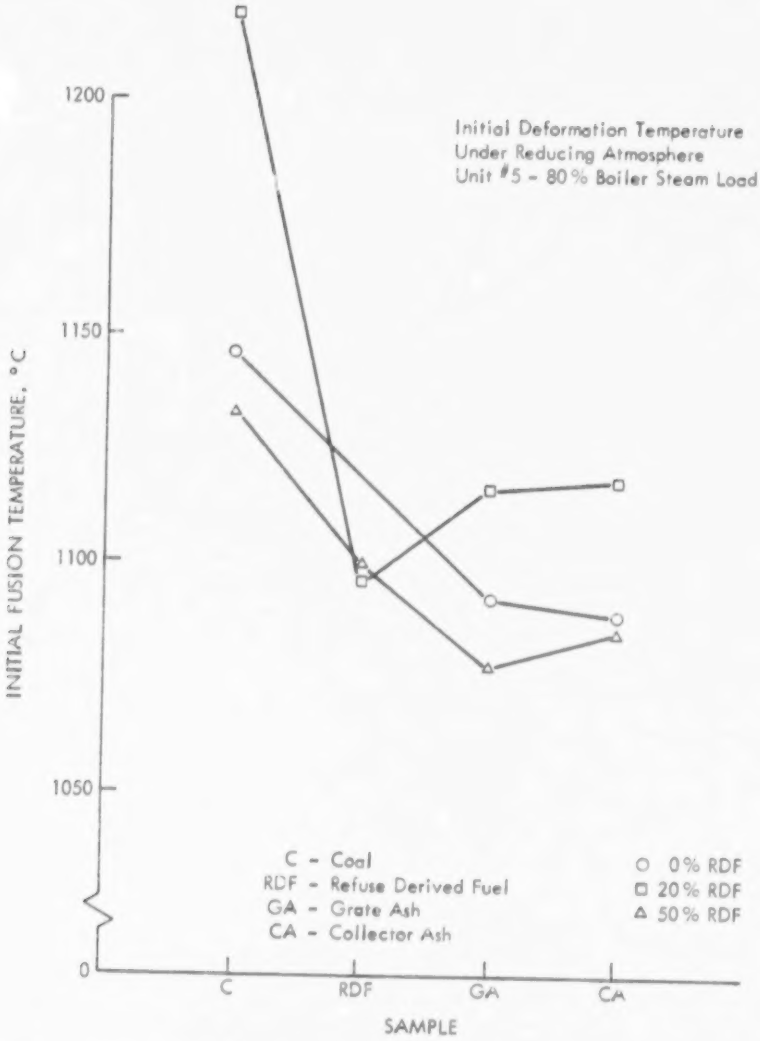


Figure 31. Initial deformation temperature, under reducing atmosphere, of boiler unit No. 5 at 80% boiler steam load.

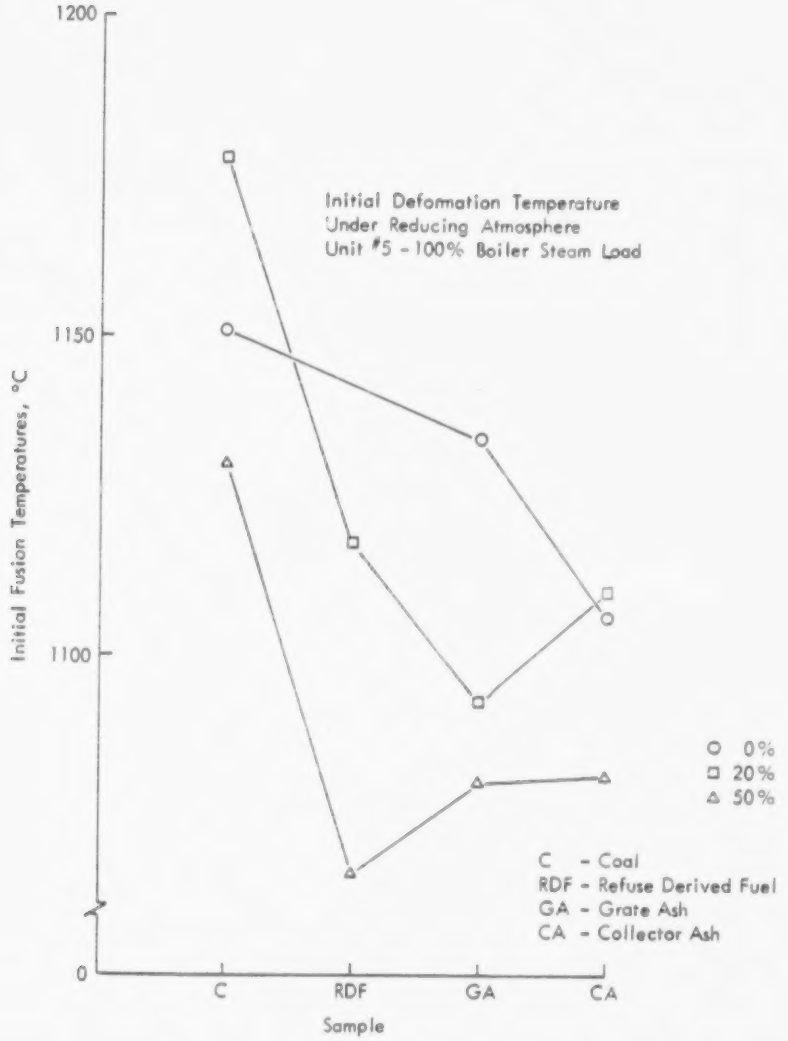


Figure 32. Initial deformation temperature, under reducing atmosphere, of boiler unit No. 5 at 100% boiler steam load.

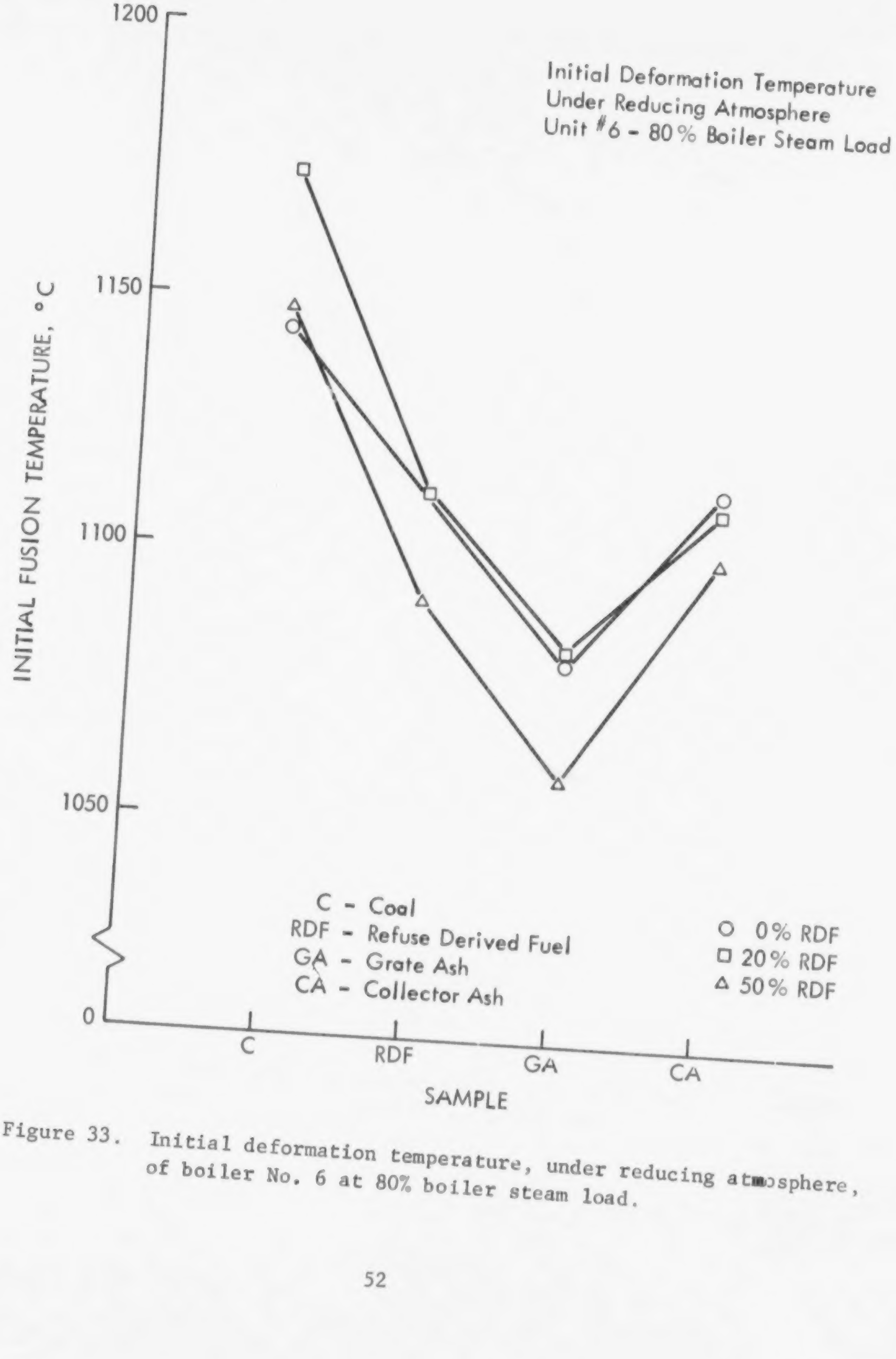


Figure 33. Initial deformation temperature, under reducing atmosphere, of boiler No. 6 at 80% boiler steam load.

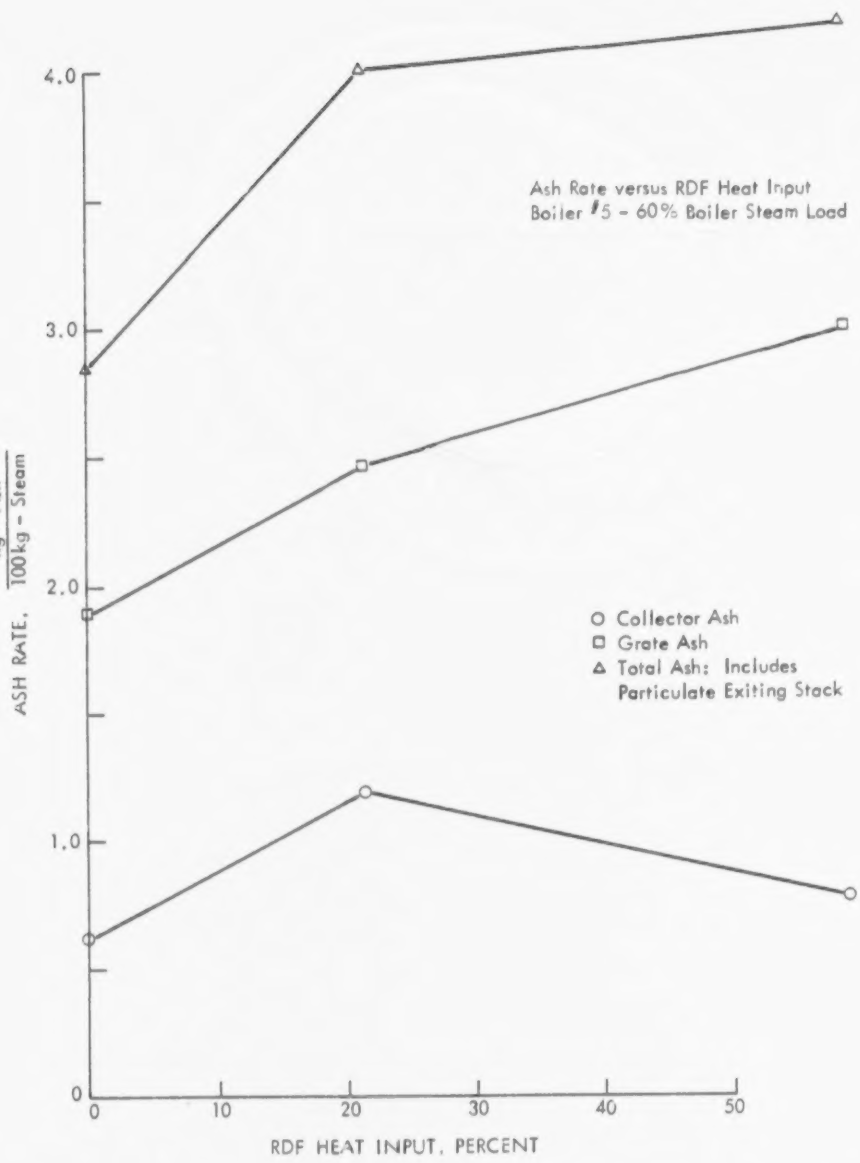


Figure 34. Ash rate of boiler unit No. 5 as a function of RDF heat input and 60% boiler steam load.

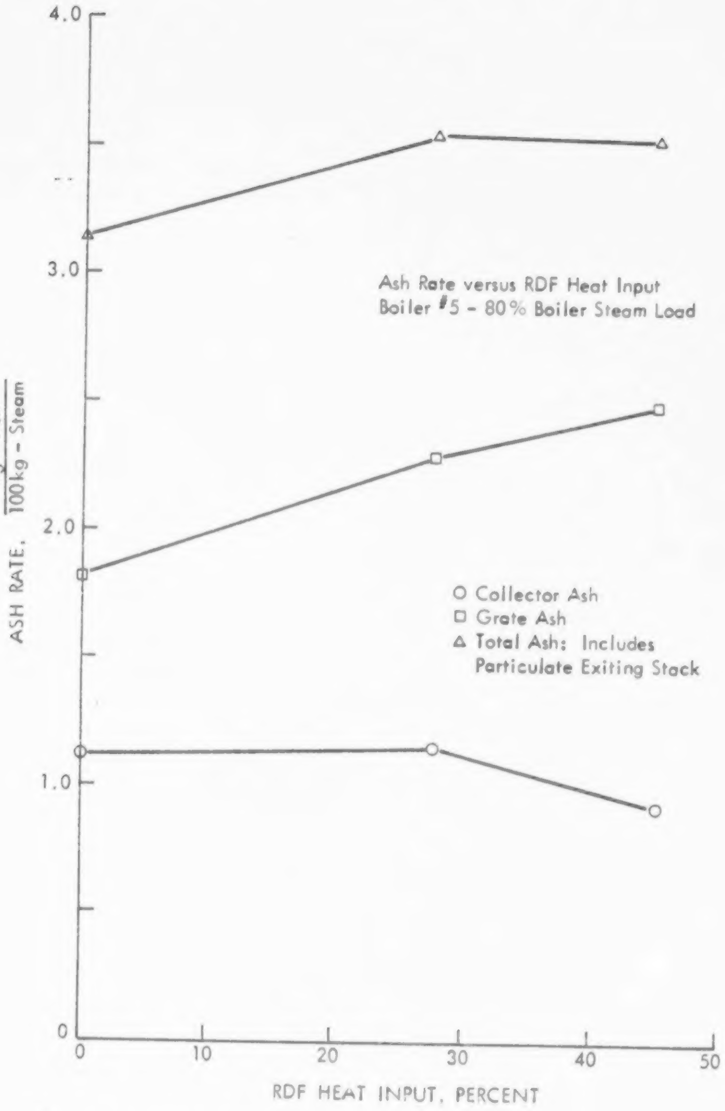


Figure 35. Ash rate of boiler unit No. 5 as a function of RDF heat input and 80% boiler steam load.

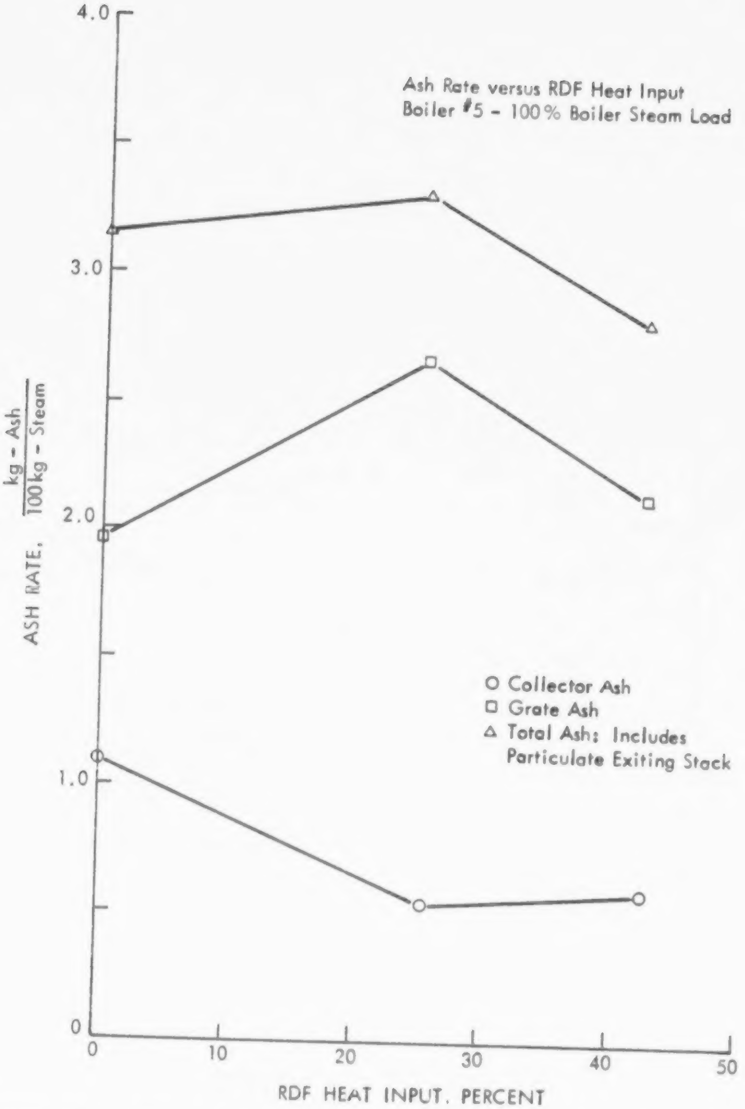


Figure 36. Ash rate of boiler unit No. 5 as a function of RDF heat input and 100% boiler steam load.

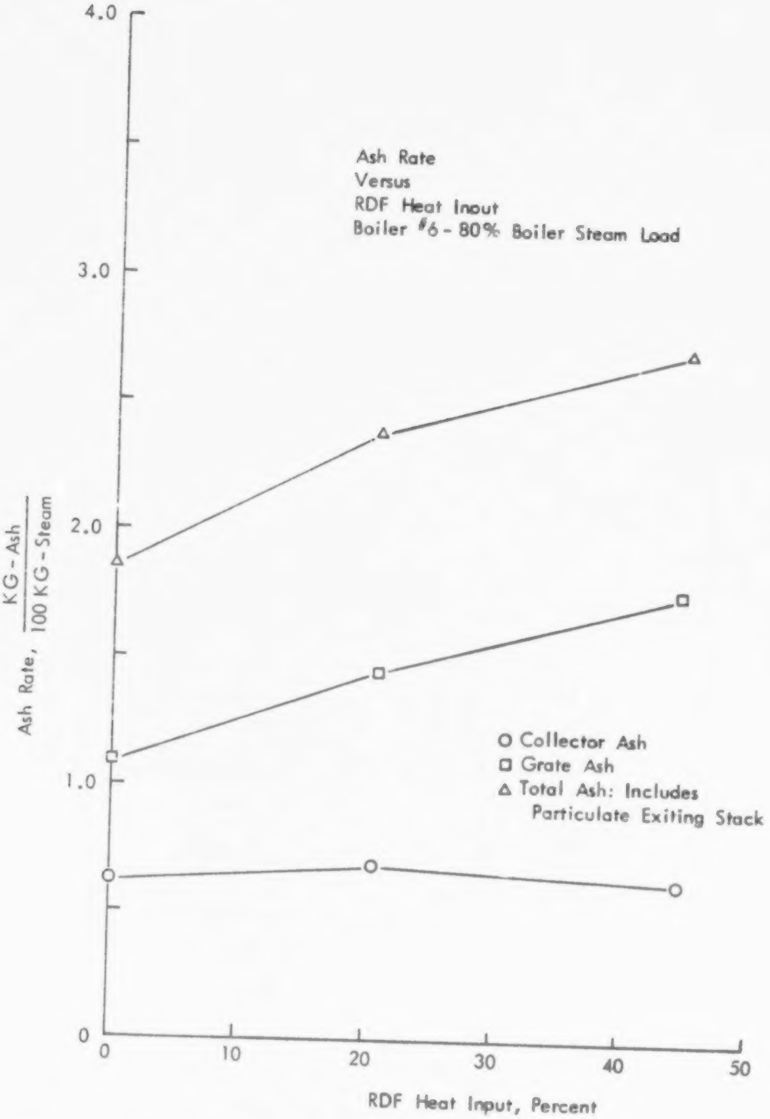


Figure 37. Ash rate of boiler unit No. 6 as a function of RDF heat input and 80% boiler steam load.

SECTION 8

CORROSION INVESTIGATION

OBJECTIVES

The basic objectives of the corrosion studies conducted to date are as follows:

- Plant protection--The detection, measurement and prevention of corrosion processes which, if allowed to continue, would create a hazard to personnel or any deterioration of the physical plant other than that associated with normal operations which do not involve the burning of refuse.
- Determination of causes of corrosion--The study of the mechanism, rate, and the processes and chemical substances associated with any corrosive attack more severe than that associated with normal operations.

It was decided not to use a test probe for obtaining corrosion data. While the use of such a probe might have generated data more directly comparable with that obtained by other researchers, it was felt that the data would not be as applicable to service conditions as was desired. Probes are fixed in their location and do not duplicate either the external or internal environments of boiler and superheater tubes. In addition, there would have been problems in shipping and disassembling probe components and interpreting data from devices built by others. Therefore in situ exposures of actual boiler and superheater tubes were used to obtain data.

EXPERIMENTAL PROCEDURES

On February 25, 1976, during a scheduled shutdown of boiler unit No. 5, several sections of waterwall boiler tube were removed and replaced with sections cut from a single piece of spare tubing. In addition, one superheater tube was also replaced using a previously unused spare tube section.

The waterwall tubing specified in the blueprints for the original unit is identified by the trade name, "Electrunite" which is a Republic Steel

Corporation trade name referring to a plain carbon steel having 0.2 to 0.3% carbon. The tube used for test purposes was a tube taken from the stock of spares. The composition was not known at the onset of the test.

Analysis of a portion of the spare waterwall tube installed for test purposes is as follows:

C - 0.12%
Mn - 0.39%
Si - 0.20%
P - 0.014%

S - 0.022%
Cr - 0.01%
Mo - 0.01%

A tube having this chemical analysis would meet the present chemical requirements for ASTM Method A178, Grade A steel or ASTM Method A192 steel.

The superheater tube test specimen was also taken from the stock of spares. The specified material for the superheater tubes is type SA209, Grade T1 carbon-molybdenum steel.

The chemical analysis of the test superheater tube is:

C - 0.10%
Mn - 0.42%
Si - 0.17%
P - 0.014%

S - 0.030%
Cr - 0.04%
Mo - 0.50%

This analysis conforms to the requirements for Grade T1 or T1b steel of ASTM Specification A209 and A250.

The test tubes were installed as replacement sections in existing waterwall and superheater tubes in regular service. Waterwall tube locations were chosen so as to provide possible reducing conditions (south wall), impingment from fuel distributors (west wall) and deposition of fines and slag from distributors (east wall). The superheater tube was installed near the center of the bank of tubes where hot gas and ash first contact the superheater.

The locations of the waterwall tube test sections were as follows:

South wall tube (later referred to as specimen No. 25)--This tube was the sixth from the west wall and was a section about 1 m long with the bottom end being very nearly 61 cm above the grate. This corresponds to a location where problems might be anticipated if there were a reducing atmosphere near the fuel bed.

East wall tube--This 1-m section had its bottom end 1.6 m above the grate and lay against the east wall between and below the fuel distributors.

West wall tube--This 1-m section was on the wall facing the fuel distributors and the bottom end was 2.4 m above the grate. The tube was the 14th from the south wall.

Superheater tube--The specimen was the 17th front superheater tube from the south side of the unit.

Firing of unit No. 5 containing the test tubes began on February 28, 1976, and ran intermittently until May 10, for a total of 1,018.5 hr. During this time the coal was approximately a 50-50 mixture of Iowa and Wyoming coal. Coal constituted 50% of the BTU input, the balance being RDF. RDF was added at the 50% BTU level in excess of 90% of the firing time.

TEST RESULTS AND ANALYSIS

Approach and Definition

The information most desired is that which measures any loss in the strength or serviceability of the tubes, especially as contrasted to the comparable loss of identical parts exposed only to the combustion products of coal. Such loss of serviceability might be expressed as uniform loss of metal thickness, local loss of metal thickness (pitting), cracking (stress-corrosion cracking, thermal stress cracking), microstructural alteration, etc. No one parameter or no small group of indexes of metal degradation should be arbitrarily selected, nor should attention be focused on some to the exclusion of others. To do so is to run the risk of overlooking important data or potential damage. Moreover, it can tend to establish one parameter of a complex process as the only valid criterion for evaluation.

The mechanism and depth of attack of metal surfaces was selected as the first index of performance. These observations are made after exposures of only one duration. Therefore, nothing can be said regarding rates of metal damage.

Making the tacit assumption that metal damage is a function of external environment, deposits and scales which remain on the metal tubes after exposure, was also evaluated. Clearly, as observed at room temperatures, these compounds do not correspond identically with the gaseous or thermal environment which existed during exposure and thus are limited expressions of the environment of exposure. However, it appears very probable that any interaction between the metal tubes and their environment can be safely assumed to be between the tubes and the solids and liquids to which they were exposed and which, to a large degree, remained on the tubes after combustion ceased.

No attempt is made in this report to relate the composition, presence or structure of deposits and scales with the fuels employed, though that is ultimately a question of importance to consider.

It should be noted that while the average composition and net amount of scales and deposits found after cooldown may be similar to those at temperature, the structure is apt to differ markedly as a consequence of mechanical factors such as thermal contraction, as well as chemical factors related to cooling in a very complex multicomponent system. After considerably more study, it may be possible to begin the extrapolation from conditions at the time of observation to those which existed during exposure.

In this report differentiation is made between scales and deposits. Scales are meant to embrace those substances formed on the surfaces of metal tubes by a chemical interaction between one or more components of the tube with some part of the environment. This can be thought of as a product of chemical attack. The product itself may also undergo subsequent changes or interactions.

Deposits, on the other hand, are regarded as materials physically located on or near the tube surface but which have not entered into chemical reactions with the tube. Thus, while they may reveal important information about the products and nature of the fuel and the combustion process, they do not materially influence the tube except indirectly such as by changing surface temperatures, altering diffusion rates, reacting with underlying scales, etc.

In this work initial attention is given to scales rather than deposits in the belief they were more directly related to actual or potentially damaging changes in the tubes themselves. Nevertheless, in part to correlate with prior work and to document the nature of the materials which constitute the effective environment of the metal tubes, some attention has been given to deposits.

Metallographic Studies of Tubes and Scales

The waterwall tube is low carbon steel having substantial decarburization and massive grains on the hot-worked external surface. The tube wall thickness varied sufficiently around the periphery so that thickness measurements could not be used to show loss of wall thickness. However, these surface features served as markers which permitted semiquantitative estimates of metal loss.

Figure 38 is a reference photograph of a piece of unused waterwall tubing showing the decarburization, large grains, and adhering mill scale, all of which persisted in exposed specimens.

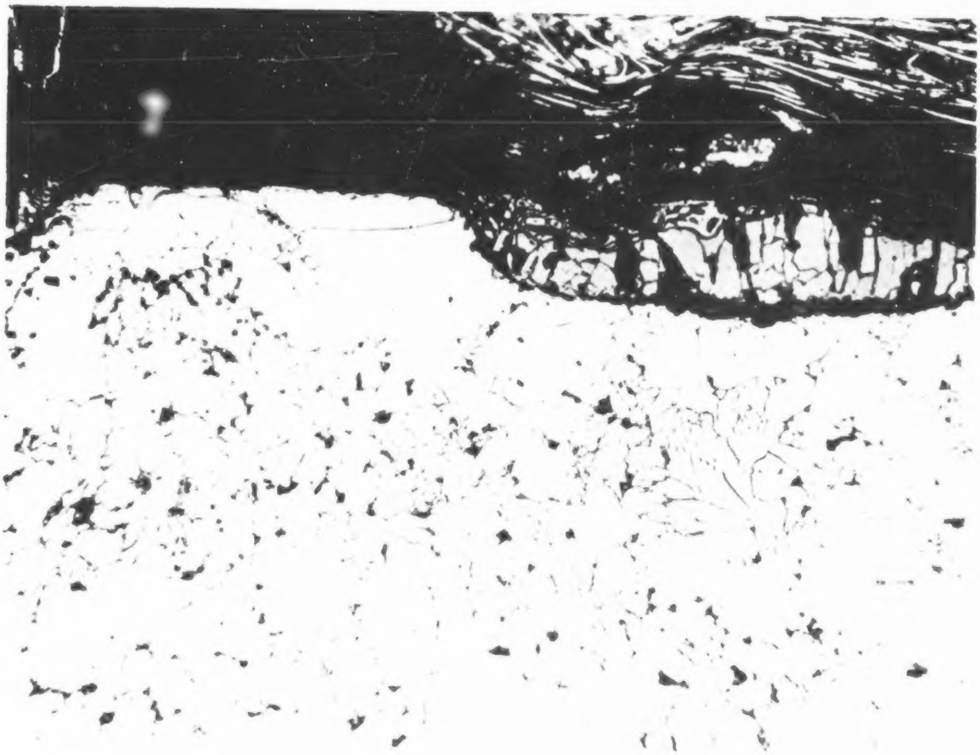


Figure 38. Outer surface of unused portion of boiler waterwall tube. (negative No. 21682).

The surface decarburization and massive grains were produced during manufacture and are means for locating the original surface. Also shown is one patch of cracked mill scale which was forced into the metal surface during tube forming. Similar patches of residual mill scale are noted on exposed samples.

250X

The site of anticipated maximum attack is the exposed face of the waterwall tube nearest the grate (sample No. 25). This is shown in Figure 39. There is a slight roughening of the surface, and a thin adherent scale has formed. However, surface loss is essentially nil. Additional photographs taken around the periphery, as exemplified by Figure 40, show diminishing surface scale and no evidence of measurable surface metal loss.

Inspection of the water side of these tubes showed that the scale was thin and adherent with no evidence of surface attack.

The scale on the superheater tube is significantly different from that on the waterwall, as shown in Figure 41. The innermost scale is black, possibly FeO. There are numerous sites where the oxide at the metal interface is cusped, shows attached spherical regions nearly enclosed by metal, or shows apparently detached (in the plane of polish) spheres of oxide lying below the metal surface. None of these features extend more than one grain into the metal and thus, are not regarded as serious, but they do represent an oxidation mechanism which is presently not understood.

Above the inner black oxide layer is a gray scale which is probably Fe_3O_4. It is distinctly layered, showing it to be a fresh scale formed in situ and not adhering mill scale. Interspersed in this scale layer is a fairly uniformly distributed second phase, light in color, and having a form suggesting that it may have been liquid at operating temperatures. Numerous regions, such as those shown in Figure 41, are found where the light phase appears to be highly concentrated. These regions are always associated with an inward curvature of the scale. The scale layers lie parallel to the curved surface, strongly suggesting that in these regions there was preferential attack of the metal with the scale forming on the surface of a hemispherical pit.

Above the two-phase, (Fe_3O_4 + light phase), layered gray scale is the original top scale , probably Fe_2O_3. It also is gray and lies parallel to the original metal surface. Closely parallel to this layer is a layer of the light phase, lying both above and (sometimes) below the Fe_2O_3 layer. Above these well defined layers is the innermost part of the heterogeneous deposit.

Figure 42 is a view of a similar scale formation formed on a section of the superheater tube adjacent to that shown in Figure 41; thus, it is not directly facing the gas flow but is more toward the side of the tube. Many of the features of the scale are the same as that shown in Figure 41, but one notable difference is the very thin layer of black oxide adjacent to the metal. The depressions corresponding to concentrations of light phase are, in this case, depressions in the metal surface.

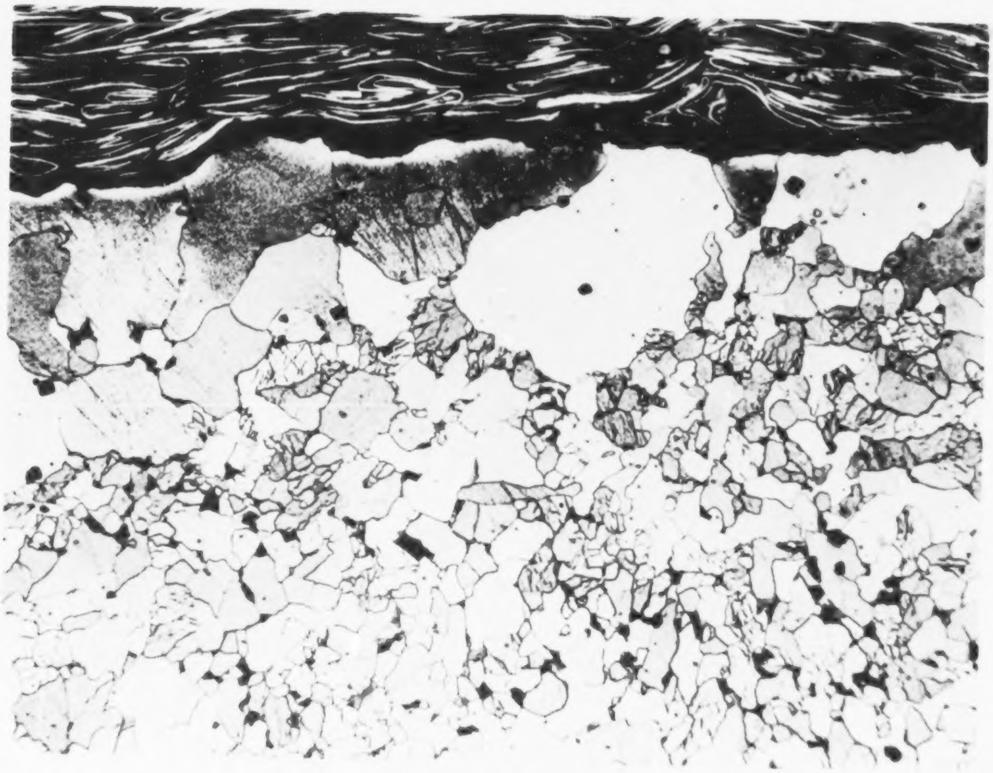


Figure 39. Exposed side of outer surface of boiler waterwall tube. (negative No. 21678).

Sample No. 25, a waterwall tube located 61 cm above the grate. Decarburization and large grains are characteristic of the original surface. A thin layer of adherent oxide is visible; other scales and deposits have fallen off during handling. Wavy lines are copper flakes embedded in plastic to form an electrically conductive mount. Loss of surface metal is nil.

250X

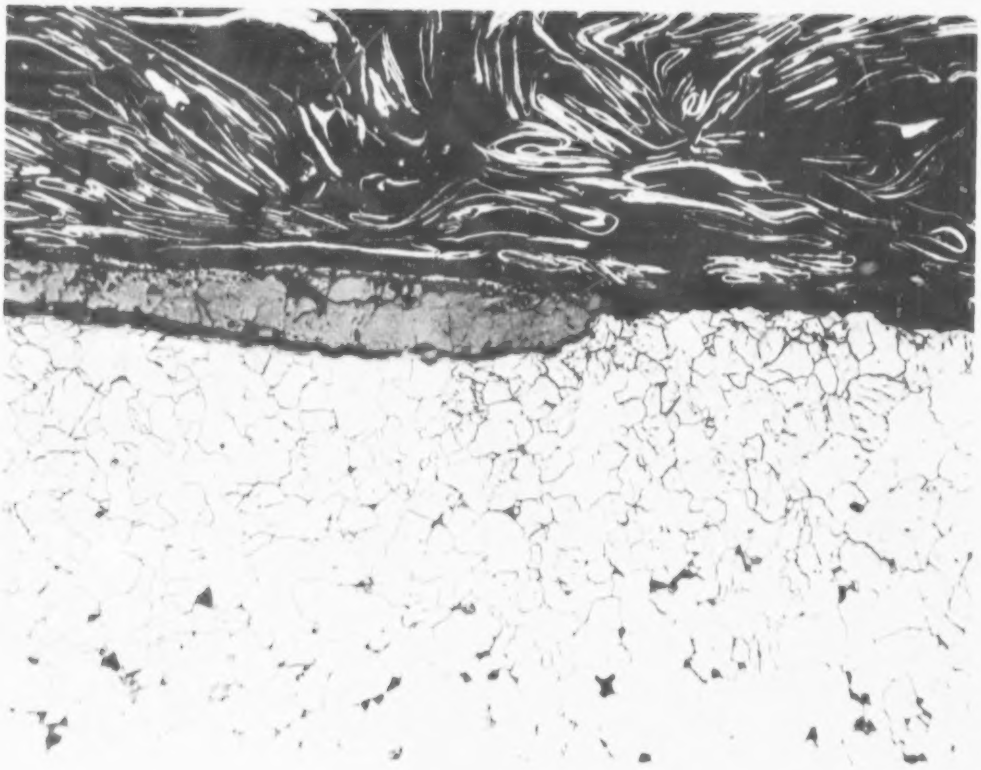


Figure 40. Exposed side of outer surface of boiler waterwall tube. (negative No. 21677).

Sample No. 25, at a position approximately 30 degrees around from the fire side toward the furnace wall side of the tube. Large grains are absent but decarburization and impressed mill scale mark original surface. Some black oxide has formed beneath the cracked gray Fe_3O_4. Metal loss is nil. 250X

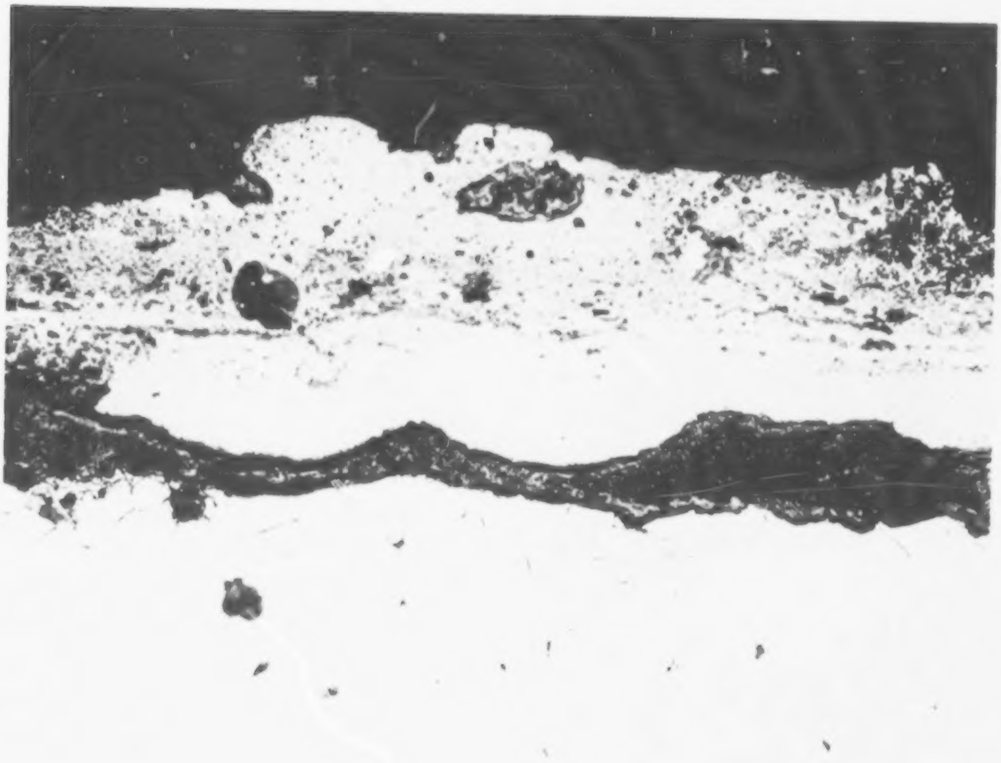


Figure 41. Exposed front face of boiler superheater tube. (negative No. 21669).

Ferritic metal substrate overlain by a layer of black iron oxide. Note some extensions of black oxide into the metal in the form of hemispherical cusps and one nearly separated subsurface sphere. Light gray layer is Fe_3O_4 containing a fine dispersion of a lighter phase which exists in greater concentration at the centers of inward-curving "dimples". Above this is a thin layer, probably Fe_2O_3, which is the uppermost scale layer. Parallel to this layer is frequently found a layer of the light phase. Above the well-defined scale layers is the heterogeneous deposit.

250X

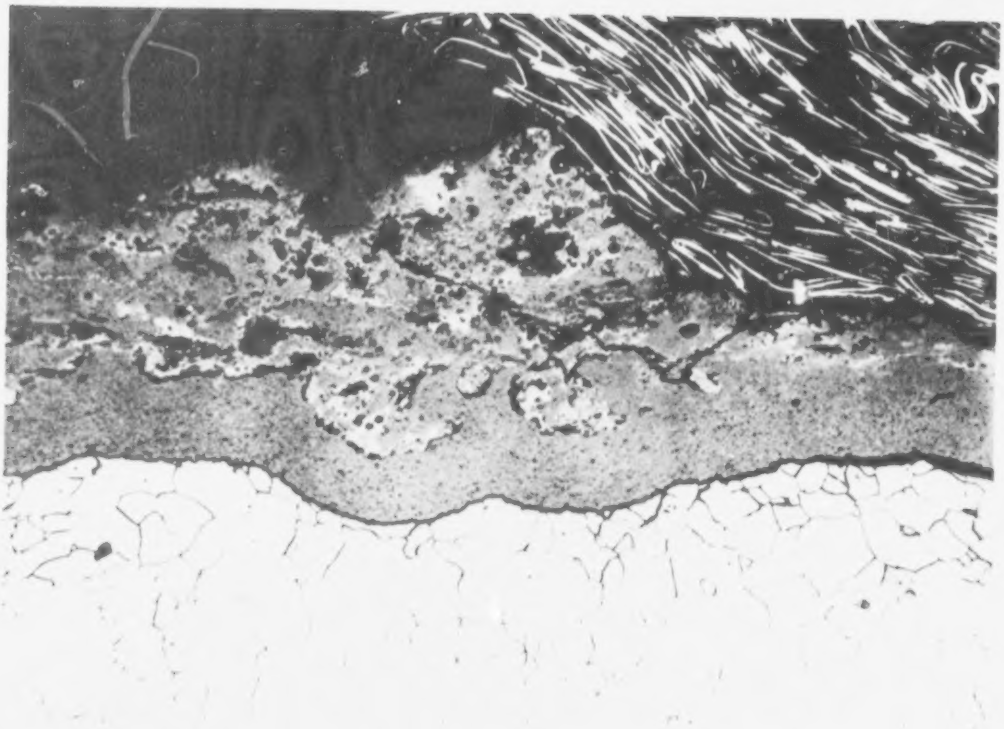


Figure 42. Scale and deposit on boiler superheater tube. (negative No. 21668).

Shown are heterogeneous deposit lying on layered, cusped scale. Note the association of concentrations of the white phase with the cusps. The black oxide layer adjacent to the metal is very thin and the scale is essentially unbroken.

250X

Figure 43, showing a region very near to that shown in Figure 42, demonstrates the observation that heavy concentrations of inner black oxide are strongly associated with cracks in the gray Fe_3O_4 layer. The amount of such cracking diminishes from the upstream (referring to gas flow over the tube) to the downstream side. Cracking and black oxide are virtually absent on the downstream side.

Combining the observations in Figures 41, 42, and 43, one is led to the conclusion that the black oxide forms only after a well-developed Fe_3O_4 layer exists and becomes cracked. In Figure 41, for example, the curvature of the inner surface of the Fe_3O_4 layer is only faintly replicated on the metal surface which has apparently been leveled by the growth and intrusion of black oxide through cracks. Where the Fe_3O_4 is not damaged, it lies directly on the metal surface.

The top layer of scale, which may be Fe_2O_3, and which apparently formed initially on the metal surface, is fairly smooth where it is observed, as in Figures 41 and 42. Where cusps in the Fe_3O_4 layers are found, as in Figures 41 and 43, they are invariably associated with white scale near the center of curvature of the cusp. As shown in Figure 41, this concentration of white scale lies below the layer of scale which was first to form. On the other hand, wherever black oxide is found, it appears to have leveled the metal surface under the Fe_3O_4 scale. In Figure 43, where black oxide is barely present, the cusped Fe_3O_4 essentially penetrates the metal and both the oxide and the metal have the same topography.

Based upon morphology only, one is led to suspect that oxide cusps, and thus pitting of the underlying metal, occur as a consequence of the white scale which may concentrate in local areas and which may form after (perhaps penetrating) the first oxide scale. For reasons unknown, the Fe_3O_4 layer may crack and separate from the metal causing new black oxide to form in the void. It is not presently known whether this oxide is FeO, as might be judged by the color, or whether it is Fe_3O_4 (or some other compound) whose appearance is black because of different morphology resulting from different conditions of formation. One difficulty with the hypothesis of the formation of FeO is that its lower temperature of stability in the binary iron-oxygen system is 550°C, well above the expected tube temperature of 500°C. Phase stability will need to be examined in the light of all major elements and compounds present in the system as well as their activities and disassociation pressures.

Preliminary microprobe data are as yet insufficient to detect the differences in Fe/O ratios of FeO and Fe_3O_4 so oxide identification is presently tentative.

After the confirmation by microprobe of the presence of sulfur in all parts of the scale, an additional set of photomicrographs was taken at higher

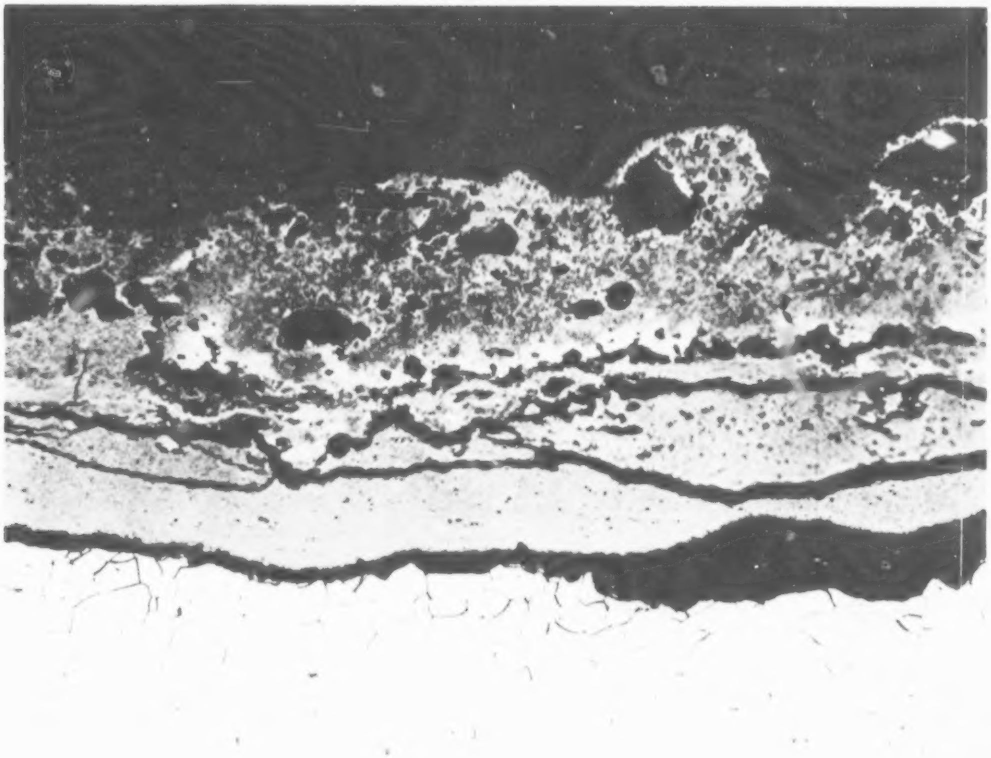


Figure 43. Scale and deposit on boiler superheater tube. (negative No. 21667).

Shown are external deposits and considerable lateral fracturing of the gray scale. Fractures are filled with black oxide. 250X magnifications in an attempt to reveal more clearly the sulfur distribution. Figures 44 through 46 are photographs at 1500X of, respectively, the Fe_3O_4 layer adjacent to the superheater tube metal at the location of a cusp, the concentration of white phase at the center of a cusp, and the scale-deposit interface away from a cusp. These photographs show conclusively that what appears to be an Fe_3O_4 layer at lower magnifications is in fact a two-phase mixture of Fe_3O_4 with a white, sulfur-rich phase. This white phase lies both above and below the thin first layer of oxide (Figure 46) and is also present at the center of cusps in a form suggestive of the presence of a liquid at high temperatures.

Further interpretation of the mechanism and kinetics of formation of this white phase will depend upon the positive identification of the phase itself and the study of its thermodynamic properties.

Microprobe Analysis of Scales and Deposits

A microprobe analysis was performed on the scale formed upon the superheater. Levels of K, Na, Ca, and Si were substantially uniform across the scale and all values fell in the range of 0.23 to 1.00% by weight, with some tendency for the higher values in the deposit as compared to the scale.

Preliminary results indicate that the black scale layer of Figure 41 contains about 5.2% S. Readings at points successively outward through the Fe_3O_4 layer show values of 11.8, 17.7, and 18.2% S, the highest concentration occurring in the vicinity of the accumulation of white phase. Sulfur content in the deposit was 17.2%. There is a corresponding decrease in iron in the scale, being highest (60%) in the inner black layer, lesser (52 to 54%) in the Fe_3O_4 layer, and lower still (29%) in the deposit.

Until methods are further refined, these numbers cannot be taken exactly, but they do show a substantial concentration of sulfur in the scale, leading to the present belief that the light phase is some type of sulfur-containing compound. Attempts to physically separate and analyze this light phase by microprobe and X-ray diffraction have not yet been successful.

Preliminary microprobe results suggest that this analytical method may be useful in establishing which elements are commonly found in the same location, thus providing a valuable supplement to X-ray diffraction analysis. For example, on several samples of scale and deposits, Ca, Si, and Al were found to be located together, suggesting formation of compounds such as $CaAl_2SO_4$; while Na and K were found in association with S, suggesting the existence of compounds such as Na_2SO_4. Results to date, however, do not warrant identification of particular compounds.

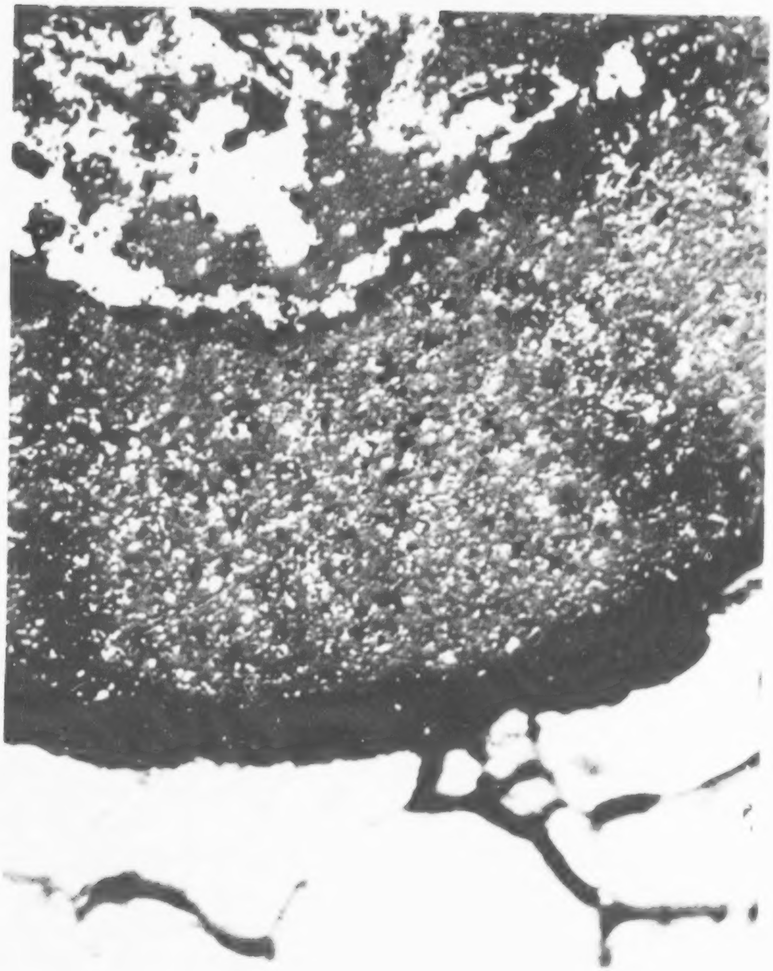


Figure 44. Bottom of scale cusp lying adjacent to metal surface of boiler superheater tube. (negative No. 21836).

Scale is two-phased with white, sulfur-rich phase uniformly dispersed. Ferrite grains are out of focus because the plane of polish of the scale differs from that of the metal. 1500X

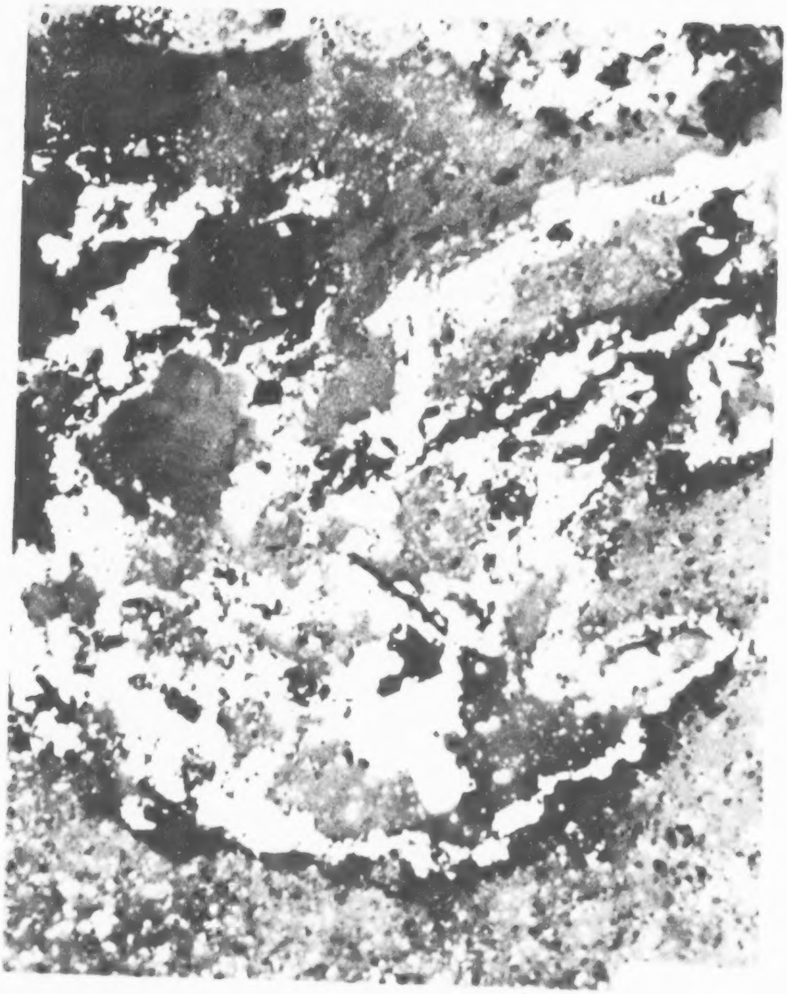


Figure 45. The region near the center of curvature of the cusp. (negative No. 21838).

Note the high concentration of the white, sulfur-rich phase and a morphology suggesting the possibility of the presence of liquid at high temperatures.

1500X

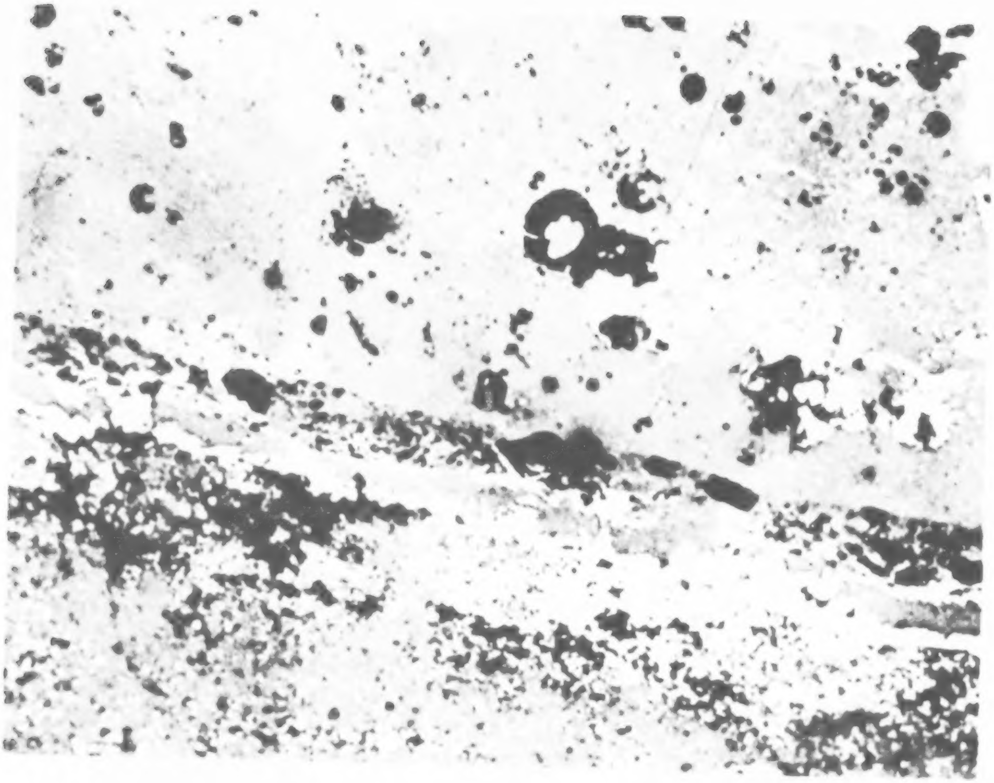


Figure 46. Scale and deposit interface on boiler superheater tube. (negative No. 21840).

This view shows a region having no underlying cusps. Note the concentration of white sulfur-rich phase above, and especially below, the thin layer of initially formed oxide. The inner scale has finely divided white phase; the deposit has larger and irregular white areas. 1500X

Bulk Chemical Analysis of Deposits

During the process of removal of the boiler tube samples, the surface deposits were lost. However, samples of deposits were obtained from many locations in unit No. 5 as part of a separate attempt to classify deposits. Samples were taken close to the locations where tubes were removed, and thus, should be reasonable approximations of the deposits which existed on the tube samples.

Sample 2 was taken from a position approximately 60 cm above the grate on the north wall. Deposit configurations on this wall were nearly mirror images of those on the south wall from which tube sample No. 25 was taken. Sample 18-C1 was taken from a superheater tube and represents inner deposit and outer scale material; while 18-C2, also from a superheater tube, is a sample of deposit material. Chemical analysis results for these samples are given in Table 2.

TABLE 2. BOILER TUBE CORROSION DEPOSIT AND SCALE ANALYSES

		Weight percent	
Element	Sample No. 2 near grate	Sample 18-C1 superheater scale	Sample 18-C2 superheater deposit
Pb	0.0016	0.840	0.580
S	0.409	12.0	9.76
Sn	0.0047	0.0160	0.0147
Zn	0.0156	0.495	0.0487
Cl	< 600 ppm	< 600 ppm	< 600 ppm
Al	7.32	4.70	5.02
Ca	7.86	7.23	9.33
Fe	9.08	26.6	7.86
K	1.12	3.31	3.54
Mg	1.19	0.688	0.736
Na	1.57	4.06	1.30

These results show that chlorine is apparently not present in scales or deposits at any significant level. Iron is present, as expected, in greater amounts in a scale sample than in deposits. Most notable however, is the high concentration of sulfur in the superheater scale and deposit, and the possible association of sodium and potassium with high sulfur levels in the scale. These gross chemical analysis results confirm the microprobe findings of high sulfur contents in both the scale and the deposit.

Discussion

While present analyses are not sufficient to warrant a positive conclusion, there is strong evidence that sulfur is the one element of concern with regard to scaling of metal tubes. It is concentrated in areas where pitting is found, it is present in greater concentrations in superheater tube scales and deposits than in waterwall deposits, and it may be associated with sodium. Liquid oxides have been found in other corrosion environments containing sodium and sulfur and we observe oxide morphologies suggesting liquid phases near pitting sites in the superheater scale. On the other hand, there is no evidence of any substantial role of chlorine in any scaling.

It should be noted that although pitting has been observed, the degree of damage in terms of metal loss or penetration is presently extremely slight. Maximum observed pit depths in superheater tubes are of the order of 0.025 mm (0.001 in.). Loss of metal from waterwall tube surfaces is much less. Althrough high sulfur levels are a cause for concern, it appears that this concern would be that catastrophic corrosion (such as is known to occur in some oxide-sulfide systems) might occur at some future time. It should be remembered that the source for sulfur in this environment is the coal and that the presence of solid waste reduces the sulfur content. Thus, since the unit in question was burning coal alone long before solid waste was introduced, the tubes have already demonstrated that they are capable of resisting even higher sulfur atmospheres for many years with no damage.

On the other hand, successful service under a higher sulfur potential is no guarantee of success at a lower one. Moreover, when the sulfur is present along with elements now present in different proportions, or present now compared with virtual absence before the introduction of solid waste fuel, corrosion problems might increase. The mere presence of a sulfur-rich phase in both the scales and deposits of the superheater is a justifiable cause for concern until the system is thoroughly understood.

As this report was being written, a new set of samples was being installed. The tubes being reported upon here were initially installed using available spares before there was adequate opportunity for measuring and examining the test tubes. The new set now being installed was thoroughly cleaned prior to installation. During this cleaning process it was found that the superheater tube had a protective coating which totally masked a highly pitted metal surface. It appears that the stock tubing had lain in water or some other corrodent to a depth of about one-third the tube diameter until considerable pitting developed at the liquid/air interface, and some had developed below the liquid surface. The corroded tube was then bent into a "U" shape and coated.

The first reaction to this discovery was to discount the finding of pits in the belief that the sulfur-rich scale did not cause pits but rather followed the contour already present. However, this does not adequately explain the fairly level initial layer of scale overlying the pit. Moreover, even if pits were initially present, if they served as sinks for sulfur there would be cause for concern.

Upon further reflection it was realized that the pitted tubes provide an opportunity for more, rather than less, reliable data. The corroded surface which lies on the upstream side of the U bend on one leg of the U, lies on the downstream side on the other. Thus, in each U sample there is the opportunity to examine both pitted and unpitted surfaces, each both facing toward and away from the stream of combustion products. These variables will be examined on both the present tube samples and those now being exposed.

SUMMARY

Examination by metallography, microbe, and chemical analysis of waterwall tubes, superheater tubes and their scales, and deposits show that during exposure to firing of a mixture of 50% coal and 50% solid waste for a period of 1,018.5 hr, the corrosion of the waterwall tubes was virtually zero. Corrosion of superheater tubes, if any, did not exceed approximately 0.025 mm. The scale on the superheater tube contained sulfur in amounts ranging up to approximately 12 to 18%. It is not known whether in this amount, and in the presence of the other elements known to also be present, this constitutes a potential for catastrophic corrosion.

Chlorine in both waterwall and superheater tube scales is present in amounts below the limit of detection of the analytical method used (<600 ppm) and is not thought to constitute a significant factor in tube corrosion.

Future work will be directed primarily toward more complete and quantitative understanding of superheater tube scales and the actual and possible mechanisms of corrosive attack by the phases found to occur.

APPENDIX A - ORIGINAL BOILER DESIGN CONDITIONS

TABLE A-1a. BOILER PERFORMANCE DESIGN - UNIT 5 (S.I. units)

Performance data - One steam generating unit, 43,091 kg of steam per hour maximum continuous capacity; 4,445 kPa operating pressure; 171°C feed water, steam temperature 443°C; fuel - Iowa Coal; moisture 15.72; V.M. 32.49; F.C. 32.98; ash 18.81; Btu as fired 9,696; ultimate analysis, C 50.50, O 6.25, S 4.15, V 0.91, H 3.66; fusion temperature ash 1,066°C.

	Ratings			
1. Kilograms of steam per hour actual evaporation	11,340	27,216	43,091	49,895
2. MJ in steam above feed water temperature	29,331	70,372	111,308	128,928
3. Temperature of gases leaving furnace, °C			1,032	1,082
4. CO_2 in boiler exit gases	12.7	13.7	13.7	13.7
5. Percent excess air in boiler exit gases	45	35	35	35
6. Temperature of boiler exit gases, °C	288	321	352	371
7. Temperature of economizer exit gases, °C	179	191	204	218
8. Temperature of water leaving economizer (enter 171°C)	213	217	224	228
9. Water pressure drop thru economizer, kPa	7	41	97	131
10. CO_2 in economizer exit gases	12.7	13.7	13.3	13.3
11. Temperature of air for combustion (room temperature) °C	27	27	27	27
12. Total steam temperature leaving superheater, °C	420	442	443	443
13. Steam pressure drop thru superheater and control, kPa	14	83	207	276
14. Boiler drum pressure, kPa	4,459	4,528	4,652	4,721
15. Draft loss thru boiler and superheater (cm H_2O)	0.25	1.40	3.05	4.06
16. Draft loss thru economizer (cm H_2O)	0.43	2.54	5.84	8.13
17. Draft loss thru dust collector (cm H_2O)	0.33	1.83	4.57	6.10
18. Draft loss thru ducts and dampers (cm H_2O)	0.25	0.33	0.76	1.01
19. Furnace draft (cm H_2O)	0.25	0.25	0.25	0.25
20. Total static suction at fan (kPa)	0.15	0.62	1.42	1.92
21. Air pressure drop thru ducts and dampers (kPa)	0.69	2.07	5.52	6.89
22. Air pressure in windboxes (kPa)	6.89	10.34	13.79	17.24

(continued)

TABLE A-1a. (continued)

	Ratings			
23. Total static pressure at fan (kPa)	0.27	0.45	0.70	0.87
24. Kilograms of fuel per hour	1,696	3,983	6,350	7,439
25. Kilograms of air per hour	17,237	37,648	59,874	70,307
26. Kilograms of gas per hour leaving unit	18,597	41,277	66,224	78,018
27. Overall efficiency complete unit percent	81.0	82.7	82.0	81.1
28. Heat release in furnace: kJ per cubic meter per hour (not including heater recovery)	242,183	566,336	905,392	1,058,154
29. Kilograms coal/m^2 grate surface per hour per hour	71.3	167.5	266.6	312.5
30. Heat released per square meter grate surface per hour	1,533,131	3,577,306	5,678,264	6,677,638
HEAT BALANCE				
31. Dry flue gas loss at exit	7.54	7.54	8.35	8.96
32. Loss due to hydrogen and fuel moisture at exit	6.10	6.14	6.20	6.26
33. Loss due to moisture in air at exit	0.18	0.19	0.20	0.22
34. Loss due to radiation	2.48	1.03	0.65	0.56
35. Loss due unburned combustibles	1.20	0.90	1.10	1.40
36. Manufacturer's margin	1.50	1.50	1.50	1.50
37. Total losses	19.00	17.30	18.00	18.90
38. Efficiencies of complete unit	81.0	82.7	82.0	81.1

Performance based on reburning the cinder carryover from boiler and dust collector.

The unit consists of P79-28 plus WW boiler, H.S. 934 m^2; plus water walls, H.S. 186 m^2; economizer, H.S. 502 m^2; superheater for 443°C; two Riley spreader traveling grate stokers 2.44 m x 5.18 m shaft centers - 24 m^2 area; four Peabody gas burners; furnace volume 150 m^3; LP-6870.

TABLE A-1b. BOILER PERFORMANCE DESIGN - UNIT 5 (English units)

Performance data - One steam generating unit, 95,000 lb of steam per hour maximum continuous capacity; 630 psig operating pressure; 340°F feed water, steam temperature 830°F; fuel - Iowa Coal; moisture 15.72; V.M. 32.49; F.C. 32.98; ash 18.81; Btu as fired 9,190; ultimate analysis, C 50.50, O 6.25, S 4.15, N 0.91, H 3.66; fusion temperature ash 1,950°F.

		Ratings			
1.	Pounds of steam per hour actual evaporation	25,000	60,000	95,000	110,000
2.	K. Btu in steam above feed water temperature	27,800	66,700	105,500	122,200
3.	Temperature of gases leaving furnace, °F			1,890	1,980
4.	CO_2 in boiler exit gases	12.7	13.7	13.7	13.7
5.	Percent excess air in boiler exit gases	45	35	35	35
6.	Temperature of boiler exit gases, °F	550	610	665	700
7.	Temperature of economizer exit gases, °F	355	375	400	425
8.	Temperature of water leaving economizer (enter 340°F)	415	423	435	442
9.	Water pressure drop thru economizer, psi	1	6	14	19
10.	CO_2 in economizer exit gases	12.7	13.7	13.3	13.3
11.	Temperature of air for combustion (room temperature) °F	80	80	80	80
12.	Total steam temperature leaving superheater, °F	788	827	830	830
13.	Steam pressure drop thru superheater and control, psi	2	12	30	40
14.	Boiler drum pressure, psig	632	642	660	670
15.	Draft loss thru boiler and superheater	0.10	0.55	1.20	1.60
16.	Draft loss thru economizer	0.17	1.00	2.30	3.20
17.	Draft loss thru dust collector	0.13	0.72	1.80	2.40
18.	Draft loss thru ducts and dampers	0.10	0.13	0.30	0.40
19.	Furnace draft	0.10	0.10	0.10	0.10
20.	Total static suction at fan (inches water gage)	0.60	2.50	5.70	7.70
21.	Air pressure drop thru ducts and dampers	0.1	0.3	0.8	1.0
22.	Air pressure in windboxes	1.0	1.5	2.0	2.5

(continued)

TABLE A-1b. (continued)

		Ratings			
23.	Total static pressure at fan (inches water gage)	1.1	1.8	2.8	3.5
24.	Pounds of fuel per hour	3,740	8,780	14,000	16,400
25.	Pounds of air per hour	38,000	83,000	132,000	155,000
26.	Pounds of gas per hour leaving unit	41,000	91,000	146,000	172,000
27.	Overall efficiency complete unit, percent	81.0	82.7	82.0	81.1
28.	Heat release in furnace: Btu per cubic foot per hour (not including heater recovery)	6,500	15,200	24,300	28,400
29.	Pounds of coal per square foot of grate surface per hour	14.6	34.3	54.6	64
30.	Heat released per square foot of grate surface per hour	135,000	315,000	500,000	588,000
	HEAT BALANCE				
31.	Dry flue gas loss at exit	7.54	7.54	8.35	8.96
32.	Loss due to hydrogen and fuel moisture at exit	6.10	6.14	6.20	6.26
33.	Loss due to moisture in air at exit	0.18	0.19	0.20	0.22
34.	Loss due to radiation	2.48	1.03	0.65	0.56
35.	Loss due to unburned combustibles	1.20	0.90	1.10	1.40
36.	Manufacturer's margin	1.50	1.50	1.50	1.50
37.	Total losses	19.00	17.30	18.00	18.90
38.	Efficiencies of complete unit	81.0	82.7	82.0	81.1

Performance based on reburning the cinder carryover from boiler and dust collector.

The unit consists of P79-28 plus WW boiler, H.S. 10,055 sq ft; plus water walls, H.S. 2,000 sq ft; economizer, H.S. 5,400 sq ft; superheater for 830° F; two Riley spreader traveling grate stokers 8 ft x 17 ft shaft centers - 256 sq ft area; four Peabody gas burners; furnace volume 5,300 cu ft; LP-6870.

TABLE A-2a. UNIT 5 FAN PERFORMANCE DESIGN

Design performance - SI units				Test block
Steam flow, kg/hr	27,216	43,091	49,895	
Forced draft fan				
kg air/hr at 38°C	37,648	59,874	70,307	80,739
m^3/min	552	881	1,034	1,189
Static pressure (N/m^2)	12,411	19,305	24,132	31,716
Fan power (watts)	5,369	13,572	20,507	32,811
Induced draft fan				
kg gas/hr	41,277	66,225	78,018	90,719
Gas temperature, °C	191	204	218	246
m^3/min	838	1,379	1,676	2,064
Fan power (watts)	12,230	45,488		119,312
Flue gas temperature, °C				
Leaving furnace		1,032	1,082	
Leaving boiler	321	352		
Leaving economizer	191	204	218	
Water temperature, °C				
Entering economizer	171	171	171	
Heat release				
Coal flow kg/hr	3,983	6,350		
Heat release (J/m^2) x 10^6 grate	30.9	49.0		

Furnace volume = 150 m^3
Grate area = 24 m^2

TABLE A-2b. UNIT 5 FAN PERFORMANCE DESIGN

Design performance - English units				Test block
Steam flow, lb/hr	60,000	95,000	110,000	
Forced draft fan				
lb air/hr at 100°F	83,000	132,000	155,000	178,000
CFM	19,500	31,100	36,500	42,000
Static pressure	1.8	2.8	3.5	4.6
Fan H.P.	7.2	18.2	27.5	41.0
Induced draft fan				
lb gas per hr	91,000	146,000	172,000	200,000
Gas temperature, °F	375	400	425	475
CFM	29,600	48,700	59,200	72,900
Fan H.P.	16.4	61.0		160.0
Flue gas temperature				
Leaving furnace		1,890	1,980	
Leaving boiler	610	665	-	
Leaving economizer	375	400	425	
Water temperature				
Entering economizer	340	340	340	
Heat release				
Coal flow, lb/hr	8,780	14,000		
Heat release Btu/ft^2 grate	315,000	500,000		

Furnace volume = 5,300 ft^3
Grate area = 256 ft^2

TABLE A-3. UNIT 5 EQUIPMENT DESIGN DETAILS

Boiler:		
Manufacturer	Riley Stoker Corporation	
Type	RP79-28 plus WW	
Heating surface	934 m^2	
Volume	150 m^2	
Economizer:		
Manufacturer	Riley Stoker Corporation	
Heating surface	5,400 sq ft	
Tube size	0.05 m O.D.	
Furnace water walls:		
Heating surface	186 m^2	
Spreader stoker:		
Manufacturer	Riley Stoker Corporation	
Type	Spreader-traveling grate	
Width x length	2 - 2.44 m x 5.18 m	
Auxiliary blowers:		
Manufacturer	Clarage	Power Eng. Co.
Type	No. 7C	No. 1420
Capacity		1.51 m^3/s
Pressure		81.3 kPa
Motor	2.2 kW	14.9 kW, 3,450 rpm
Use	Cinder return	Overfire air
Fly ash collector:		
Manufacturer	Western Precipitation Corporation	
Type	Multiple cycle 9VG12	
Size	108-6	
Forced draft fan:		
Manufacturer	American Blower Corporation	
Type	No. 360 double inlet double width type HS series 82 class II heavy duty	
Rated speed	1,120 rpm	
Motor	37.3 kW, 1,200 rpm	
Drive manufacturer	American Blower Corporation	
Drive type	Type No. 18	
Induced draft fan:		
Manufacturer	American Blower Corporation	
Type	7-1/2 double inlet 2/3 double width	
Rated speed	835 rpm	
Motor	111.9 kW, 900 rpm	
Drive manufacturer	American Blower Corporation	
Drive type	Type No. 27	

TABLE A-4a. UNIT 6 FAN PERFORMANCE DESIGN

Design performance - SI units			
Steam flow, kg/hr	18,144	36,287	56,699
Flow rates			
Air, kg/hr	25,038	48,081	73,936
Coal, kg/hr	2,712	5,398	8,346
Flue gas, kg/hr	27,941	53,977	83,089
Temperature, °C			
Gas leaving boiler		293	324
Gas leaving economizer		179	210
Fan performance			
Forced draft fan			
kg air/hr at 38°C	25,038	48,081	73,936
m^3/min	348	668	1,025
Fan power (watts)	4,847	11,931	27,218
Induced draft fan			
kg gas/hr	27,941	53,977	83,089
Gas temperature, °C	149	179	210
m^3/min	532	1,110	1,798
Static suction (N/m^2)	5,860	21,856	51,780
Fan power (watts)	17,151	50,708	111,109

TABLE A-4b. UNIT 6 FAN PERFORMANCE DESIGN

Design performance - English units			
Steam flow lb/hr	40,000	80,000	125,000
Flow rates			
Air, lb/hr	55,200	106,000	163,000
Coal, lb/hr	5,980	11,900	18,400
Flue gas, lb/hr	61,600	119,000	183,200
Temperatures, °F			
Gas leaving boiler		560	615
Gas leaving economizer		355	410
Fan performance			
Forced draft fan			
lb air/hr at 100°F	55,200	106,000	163,000
CFM	12,300	23,600	36,200
BHP	6.5	16.0	36.5
Induced draft fan			
lb gas/hr	61,600	119,000	183,200
Gas temperature, °F	300	355	410
CFM	18,800	39,200	63,500
Static suction	0.85	3.17	7.51
BHP	23	68	149

TABLE A-5. UNIT 6 EQUIPMENT DESIGN DETAILS

Boiler:	
Manufacturer	Union Iron Works
Type	"VO" single pass
Heating surface	1,297 m^2
Tube size	0.06 m OD
Drum size	1.37 m ID and 1.07 m ID
Superheater:	
Manufacturer	Union Iron Works
Type	2 - Stage, pendent
Temperature control	Mud-drum, heat exchanger
Heating surface	About 214 m^2
Tube size	0.05 m
Economizer:	
Manufacturer	Union Iron Works
Type	Extended surface, field assembled
Heating surface	1,347 m^2
Tube size	0.05 m
Furnace water walls:	
Heating surface (projected)	
Side walls	43 m^2
Rear walls	14 m^2
Front walls	28 m^2
Tube size and spacing	0.09 m OD on 0.15 m centers
Spreader stoker:	
Manufacturer	Hoffman Combustion Engineering Company
Type	4 C - CAD, continuous ash discharge
Width x length	4.62 m x 5.33 m
Drives	2-Reeves (stoker), 1-Reeves (grate)
Auxiliary blower:	
Manufacturer	Buffalo Forge Company
Type	No. 35 - 5 - CD
Capacity	1.79 m^3/s
Pressure	6.73 kPa
Motor	18.6 kW
Use	Overfired air and reinjection
Fly ash collector:	
Manufacturer	American Blower Corporation
Type	Mechanical, series No. 342
Size	20 WG

(continued)

TABLE A-5. (continued)

Gas burners:	
Manufacturer	The Engineer Company
Type	K-24, gun type
Number and size	Four, No. 3 size
Gas pressure rating, kPa	117 kPa
Forced draft fan:	
Manufacturer	American Blower Corporation
Type	No. 397 DI, Series 82 HS
Rated speed	1,150 rpm
Motor kw and mfr.	44.7 - General Electric
Drive mfr. and type	American Blower Corporation Gyrol No. 171F5R
Induced draft fan:	
Manufacturer	American Blower Corporation
Type	No. 511 DI, Series 90 Sirocco
Rated speed, rpm	860
Motor	186 kW - General Electric
Drive mfr. and type	American Blower Corporation Gyrol No. 280F8R

APPENDIX B - BOILER DESIGN CONDITIONS AFTER MODIFICATION FOR RDF FIRING

TABLE B-1. BOILER PERFORMANCE DESIGN

SI units	Boiler number	
	5	6
Steam flow $\left(\frac{kg}{hr} \times 10^3\right)$	40	57.4
Outlet steam conditions $\left(\frac{N}{m^2}/°C\right)$	$4.2 \times 10^6/439$	$4.37 \times 10^6/444$
Heat input ($J \times 10^9$)		
Coal	61	93
Refuse	60	93
Total	120	190
Fuel flow ($kg/hr \times 10^3$)		
Coal	2.8	4.2
Refuse	5.2	8.0
Excess air	50	30
Air flow ($kg/hr \times 10^3$)		
Overfire air	As required	As required
Conveyor transport	NA	NA
Mill tempering	NA	NA
A.H. leakage	NA	NA
F.D. fan	55 a/	73 a/
Total air flow	55	73
English units		
Steam flow, pph $\times 10^3$	88	126.5
Outlet steam conditions, psi/°F	609/823	634/831
Heat input, Btu $\times 10^6$		
Coal	58	88
Refuse	57	88
Total	117	176

(continued)

TABLE B-1. (continued)

English units	Boiler number	
	5	6
Fuel flow, pph x 10^3		
Coal	6.1	9.3
Refuse	11.4	17.6
Excess air, %	50	30
Air flow, pph x 10^3		
Overfire air	As required	As required
Conveyor transport air	NA	NA
Mill Tempering	NA	NA
A.H. leakage	NA	NA
F.D. fan	122[a]	162[a]
Total air flow	122	162

[a] Minus overfire air flow.

TABLE B-2. PNEUMATIC TRANSPORT SYSTEM

	Boiler number	
	5	6
Furnished by	Owner	
Pipe size, in mm (in.)	203 (8)	203 (8)
Number of pipes	2	2
Refuse handling capacity, each pipe, maximum kg/hr (lb/hr)	3,629 (8,000)	3,629 (8,000)
Transport air flow rate, each pipe m^3/min (scfm)	40 (1,400)	40 (1,400)
Transport air velocity, m/sec (ft/sec)	36.6 (120)	36.6 (120)

TABLE B-3. OVERFIRE AND DISTRIBUTOR AIR SYSTEM

Overfire air		
m^3/min (scfm)	92.74 (3,275)	155.74 (5,500)
kW (BHP)	17.2 (23)	50.7 (68)
Static pressure, mm H_2O (in. H_2O)	711 (28)	1,067 (42)
N, rpm	3,480	1,770
Manufacturer; Zurn	1312-B Type O	1325-A Type O
Silencer; Aerocoustic Corporation	CI 3.3-2	CI 5.5-4
Distributor air		
m^3/min (scfm)	45.31 (1,600)	56.63 (2,000)
kW (bhp)	6.0 (8)	8.9 (12)
Static pressure, mm H_2O (in. H_2O)	432 (17)	610 (24)
N, rpm	3,480	3,480
Manufacturer; Zurn	9SS	1311-A Type O
Silencer; Aerocoustic Corporation	CI 1.6-3	CI 2.1

APPENDIX C - MAJOR BOILER PERFORMANCE

TABLE C-1. BOILER EPA TEST MATRIX DESIGNATION

Date	Boiler unit	% Load	Fuel[a]	% Refuse	Test designation
6- 8-76	No. 5	60%	C + RDF	50%	EPA 1
6-10-76	No. 5	80%	C + RDF	50%	EPA 2
6-15-76	No. 5	100%	C + RDF	50%	EPA 3
6-17-76	No. 5$^{\text{B-B}}$[d]	60%	C	0%	EPA 4[d] A and B
6-21-76	No. 5	80%	C	0%	EPA 5
6-23-76	No. 5	80%	C + RDF	20%	EPA 6
6-25-76	No. 5	100%	C + RDF	20%	EPA 7
6-28-76	No. 5	60%	C + RDF	20%	EPA 8
6-30-76	No. 5$^{\text{B-B}}$[d]	60%	C + RDF	20%	EPA 9[d] A and B
7- 2-76	No. 5	80%	C + RDF	50%	EPA 10
7- 6-76	No. 5	100%	C	0%	EPA 11
7- 8-76	No. 5$^{\text{B-B}}$[d]	80%	C + RDF	20%	EPA 12[d]
7- 8-76	No. 5$^{\text{B-B}}$[d]	80%	C + RDF	20%	EPA 13[d]
7-16-76	No. 5	100%	C + RDF	20%	EPA 14
7-17-76	No. 5	80%	C + RDF	50%	EPA 15
7-19-76	No. 5$^{\text{B-B}}$[d]	80%	C	0%	EPA 16[d]
7-19-76	No. 5$^{\text{B-B}}$[d]	80%	C	0%	EPA 17[d]
7-23-76	No. 5	100%	C + RDF	50%	EPA 18
7-24-76	No. 5	100%	C + RDF	20%	EPA 19[c]
8- 2-76	No. 5$^{\text{B-B}}$[d]	60%	C	0%	EPA 20[d]
8- 2-76	No. 5$^{\text{B-B}}$[d]	60%	C	0%	EPA 21[d,b]
8-26-76	No. 5	60%	C + RDF	50%	EPA 1-Supp.
8- 5-76	No. 6	80%	C + RDF[a]	50%	EPA 22
8- 6-76	No. 6	80%	C + RDF	50%	EPA 23
8- 9-76	No. 6	80%	C	0%	EPA 24
8-10-76	No. 6	80%	C + RDF	20%	EPA 25
8-11-76	No. 6	80%	C + RDF	20%	EPA 26
8-12-76	No. 6	80%	C + RDF	20%	EPA 27
8-13-76	No. 6	80%	C + RDF	50%	EPA 28
8-16-76	No. 6	80%	C	0%	EPA 29
8-18-76	No. 6	80%	C	0%	EPA 30

(continued)

TABLE C-1. (continued)

Date	Boiler unit	% Load	Fuel[a]	% Refuse	Test designation
8-24-76	No. $5^{\text{B-B}}$[d]	100%	C	0%	EPA 31[d]
8-24-76	No. $5^{\text{B-B}}$[d]	100%	C	0%	EPA 32[d]
8-25-76	No. 5	60%	C + RDF	20%	EPA 33
8-26-76	No. $5^{\text{B-B}}$[d]	60%	C + RDF	50%	EPA 34[d]
8-26-76	No. $5^{\text{B-B}}$[d]	60%	C + RDF	50%	EPA 35[d]
8-27-76	No. 5	60%	C	0%	EPA 36

[a] Coal for tests on boiler No. 5 is Iowa coal; on No. 6, 50% Wyoming and 50% Iowa coal.

[b] Test conducted while pulling ash to determine if boiler performance and emissions change when ash is pulled.

[c] Boiler load dropped and test terminated early.

[d] B-B indicates back-to-back testing.

TABLE C-2a. ULTIMATE ANALYSIS OF COAL

EPA test	% Load/ % RDF	Heating value kj/kg fuel	Moisture kg/kg fuel	Ash content kg/kg fuel	Carbon kg/kg fuel	Hydrogen kg/kg fuel	Oxygen kg/kg fuel	Sulfur kg/kg fuel	Chlorine kg/kg fuel
UNIT 5 - COAL									
4A	60/0	20,900	0.142	0.199	0.482	0.0347	0.0688	0.0738	NT
4B	60/0	20,900	0.142	0.199	0.482	0.0347	0.0688	0.0738	NT
20	60/0	21,500	0.133	0.180	0.512	0.0397	0.0498	0.085	0.00058
21	60/0	20,800	0.150	0.180	0.496	0.0279	0.0933	0.0516	0.00049
36	60/0	20,900	0.119	0.226	0.498	0.0321	0.0634	0.0614	0.00068
Avg.		21,000	0.137	0.197	0.494	0.0338	0.0688	0.0691	0.00058
σ		282.8	0.012	0.019	0.013	0.0043	0.0157	0.0129	0.00010
8	60/20	21,400	0.149	0.187	0.495	0.0312	0.0706	0.068	NT
9A	60/20	21,000	0.148	0.198	0.505	0.0316	0.0516	0.0656	NT
9B	60/20	20,900	0.149	0.196	0.492	0.0389	0.0576	0.0656	NT
33	60/20	20,400	0.124	0.207	0.494	0.0341	0.0737	0.0664	0.00049
Avg.		20,925	0.143	0.197	0.497	0.0340	0.0634	0.0664	0.00049
σ		411.3	0.012	0.008	0.006	0.0035	0.0105	0.0011	0
1	60/50	21,400	0.105	0.223	0.489	0.0421	0.0733	0.0673	NT
34	60/50	21,900	0.118	0.192	0.514	0.0359	0.0802	0.0592	0.00058
35	60/50	21,600	0.114	0.195	0.521	0.0375	0.0758	0.0562	0.00049
Avg.		21,633	0.112	0.203	0.508	0.0385	0.0764	0.0609	0.00054
σ		251.7	0.007	0.017	0.017	0.0032	0.0035	0.0057	0.00006
5	80/0	21,600	0.154	0.181	0.498	0.0294	0.0792	0.0591	NT
16	80/0	20,800	0.134	0.200	0.498	0.034	0.0739	0.0596	0.00039
17	80/0	20,800	0.136	0.199	0.496	0.0335	0.0726	0.062	0.00049
Avg.		21,067	0.141	0.193	0.497	0.0323	0.0764	0.0602	0.00054
σ		461.9	0.011	0.011	0.001	0.0025	0.0035	0.0016	0.00007
6	80/20	21,700	0.142	0.192	0.503	0.0362	0.0604	0.0662	NT
12	80/20	21,300	0.143	0.197	0.497	0.0408	0.0568	0.0659	NT
13	80/20	21,400	0.134	0.192	0.508	0.0416	0.0581	0.0671	NT
Avg.		21,467	0.140	0.194	0.503	0.0395	0.0584	0.0664	0
σ		208.2	0.005	0.003	0.006	0.0029	0.0018	0.0006	0
2	80/50	20,700	0.156	0.197	0.473	0.0299	0.0630	0.0814	NT
10	80/50	21,700	0.122	0.194	0.505	0.0342	0.0797	0.0647	0.00039
15	80/50	21,000	0.146	0.190	0.504	0.0359	0.0689	0.0554	0.00049
Avg.		21,133	0.141	0.194	0.494	0.0333	0.0705	0.0672	0.00044
σ		513.2	0.017	0.004	0.018	0.0031	0.0085	0.0132	0.00007

(continued)

TABLE C-2a. (continued)

EPA test	% Load/ % RDF	Heating value kj/kg fuel	Moisture kg/kg fuel	Ash content kg/kg fuel	Carbon kg/kg fuel	Hydrogen kg/kg fuel	Oxygen kg/kg fuel	Sulfur kg/kg fuel	Chlorine kg/kg fuel
11	100/0	21,700	0.132	0.193	0.508	0.0358	0.070	0.0605	0.00126
31	100/0	20,800	0.137	0.194	0.515	0.0345	0.0566	0.0618	0.00049
32	100/0	20,800	0.127	0.221	0.496	0.0354	0.0555	0.0651	0.00039
Avg.		21,100	0.132	0.203	0.506	0.0352	0.0607	0.0625	0.00071
σ		519.6	0.005	0.016	0.010	0.007	0.0081	0.0024	0.00048
7	100/20	20,600	0.135	0.203	0.497	0.274	0.0706	0.0661	0.00058
14	100/20	22,400	0.117	0.175	0.531	0.0368	0.0756	0.0636	0.00058
19	100/20	21,000	0.138	0.196	0.508	0.0416	0.0526	0.0627	0.00058
Avg.		21,333	0.130	0.191	0.512	0.0353	0.0663	0.0641	0.00058
σ		945.2	0.011	0.015	0.017	0.0072	0.0121	0.0018	0.0
3	100/50	20,200	0.162	0.209	0.478	0.0281	0.055	0.0679	NT
18	100/50	22,100	0.111	0.192	0.53	0.0428	0.0635	0.06	0.00068
Avg.		21,150	0.137	0.201	0.504	0.0355	0.0593	0.0640	0.00068
σ		1,344	0.036	0.012	0.037	0.0104	0.0060	0.0056	0.0
UNIT 6 - COAL									
24	80/0	21,700	0.183	0.113	0.524	0.0361	0.111	0.0320	0.00058
29	80/0	21,900	0.181	0.104	0.529	0.0479	0.109	0.0283	0.00049
30	80/0	20,800	0.185	0.124	0.511	0.0366	0.0966	0.0462	0.00049
Avg.		21,467	0.183	0.114	0.521	0.0402	0.106	0.0355	0.0052
σ		585.9	0.002	0.010	0.009	0.0067	0.008	0.0094	0.00005
25	80/20	21,200	0.192	0.114	0.512	0.0348	0.118	0.0293	0.00039
26	80/20	21,700	0.187	0.104	0.528	0.0326	0.114	0.0344	0.00049
27	80/20	21,600	0.169	0.131	0.527	0.035	0.101	0.0364	0.00039
Avg.		21,500	0.183	0.116	0.522	0.0341	0.111	0.0334	0.00042
σ		264.5	0.012	0.014	0.009	0.0013	0.009	0.0037	0.00006
22	80/50	21,600	0.191	0.108	0.521	0.040	0.107	0.0321	0.00068
23	80/50	22,200	0.160	0.127	0.540	0.0334	0.0999	0.0383	0.00068
28	80/50	21,700	0.187	0.0994	0.528	0.0367	0.124	0.0253	0.00029
Avg.		21,833	0.179	0.111	0.530	0.0367	0.110	0.0319	0.00055
σ		321.4	0.017	0.014	0.010	0.0033	0.012	0.0065	0.00023

NT = Not tested.

TABLE C-2b. ULTIMATE ANALYSIS OF REFUSE-DERIVED FUEL

EPA test	% Load/ % RDF	Heating value kj/kg fuel	Moisture kg/kg fuel	Ash content kg/kg fuel	Carbon kg/kg fuel	Hydrogen kg/kg fuel	Oxygen kg/kg fuel	Sulfur kg/kg fuel	Chlorine kg/kg fuel	Density kg/m^3
UNIT 5 - RDF										
4A	60/0	0	0	0	0	0	0	0	0	0
4B	60/0	0	0	0	0	0	0	0	0	0
20	60/0	0	0	0	0	0	0	0	0	0
21	60/0	0	0	0	0	0	0	0	0	0
36	60/0	0	0	0	0	0	0	0	0	0
Avg.		0	0	0	0	0	0	0	0	0
σ		0	0	0	0	0	0	0	0	0
8	60/20	12,400	0.229	0.161	0.279	0.0166	0.306	0.0062	0.0026	129
9A	60/20	13,200	0.233	0.135	0.295	0.0173	0.315	0.0026	0.0019	124
9B	60/20	13,200	0.233	0.135	0.295	0.0173	0.315	0.0026	0.0019	113
33	60/20	16,000	0.146	0.113	0.354	0.0288	0.354	0.0025	0.0021	122
Avg.		13,700	0.210	0.136	0.306	0.0200	0.323	0.0035	0.0021	122
σ		1,579	0.043	0.020	0.033	0.0058	0.021	0.0018	0.0003	6.8
1	60/50	13,300	0.191	0.184	0.319	0.0326	0.270	0.0019	0.0019	123
34	60/50	14,300	0.203	0.139	0.316	0.0188	0.318	0.0022	0.0024	116
35	60/50	13,300	0.259	0.173	0.313	0.0182	0.233	0.0024	0.0016	123
Avg		13,633	0.218	0.165	0.316	0.0232	0.274	0.0022	0.0020	120
σ		577.4	0.036	0.023	0.003	0.0081	0.043	0.0003	0.0004	3.8
5	80/0	0	0	0	0	0	0	0	0	0
16	80/0	0	0	0	0	0	0	0	0	0
17	80/0	0	0	0	0	0	0	0	0	0
Avg.		0	0	0	0	0	0	0	0	0
σ		0	0	0	0	0	0	0	0	0
6	80/20	12,900	0.211	0.209	0.295	0.0228	0.256	0.0049	0.002	130
12	80/20	13,700	0.207	0.149	0.298	0.0231	0.318	0.0032	0.0023	140
13	80/20	13,100	0.195	0.152	0.314	0.0248	0.308	0.0036	0.0023	120
Avg.		13,233	0.204	0.170	0.302	0.0236	0.294	0.0039	0.0022	130
σ		416.3	0.008	0.034	0.010	0.0011	0.033	0.0009	0.0002	9.7
2	80/50	13,000	0.239	0.137	0.290	0.0198	0.308	0.0028	0.0023	126
10	80/50	13,900	0.197	0.166	0.293	0.0242	0.311	0.0047	0.0034	124
15	80/50	12,700	0.211	0.208	0.313	0.0232	0.238	0.0037	0.0027	125
Avg		13,200	0.216	0.170	0.299	0.0224	0.286	0.0037	0.0037	125
σ		624.5	0.021	0.036	0.013	0.0023	0.041	0.0010	0.0006	1.2

(continued)

TABLE C-2b. (continued)

EPA test	% Load/ % RDF	Heating value kj/kg fuel	Moisture kg/kg fuel	Ash content kg/kg fuel	Carbon kg/kg fuel	Hydrogen kg/kg fuel	Oxygen kg/kg fuel	Sulfur kg/kg fuel	Chlorine kg/kg fuel	Density kg/m^3
11	100/0	0	0	0	0	0	0	0	0	0
31	100/0	0	0	0	0	0	0	0	0	0
32	100/0	0	0	0	0	0	0	0	0	0
Avg.		0	0	0	0	0	0	0	0	0
σ		0	0	0	0	0	0	0	0	0
7	100/20	12,900	0.215	0.154	0.373	0.037	0.211	0.0082	0.0023	111
14	100/20	12,900	0.229	0.169	0.299	0.0195	0.278	0.003	0.0025	138
19	100/20	11,500	0.192	0.242	0.308	0.0251	0.227	0.004	0.0018	126
Avg.		12,433	0.212	0.188	0.327	0.0272	0.240	0.0051	0.0022	125
σ		808	0.019	0.047	0.040	0.0089	0.035	0.0028	0.0004	14
3	100/50	11,100	0.301	0.171	0.283	0.0230	0.214	0.0043	0.0032	140
18	100/50	11,700	0.226	0.191	0.285	0.0174	0.265	0.009	0.0052	126
Avg.		11,400	0.264	0.181	0.284	0.0202	0.240	0.0067	0.0042	133
σ		424	0.053	0.014	0.001	0.0040	0.036	0.0033	0.0014	10
UNIT 6 - RDF										
24	80/0	0	0	0	0	0	0	0	0	0
29	80/0	0	0	0	0	0	0	0	0	0
30	80/0	0	0	0	0	0	0	0	0	0
Avg.		0	0	0	0	0	0	0	0	0
σ		0	0	0	0	0	0	0	0	0
25	80/20	13,200	0.202	0.136	0.324	0.0162	0.316	0.0037	0.002	111
26	80/20	13,000	0.228	0.162	0.304	0.0217	0.278	0.0039	0.0029	136
27	80/20	12,800	0.235	0.155	0.298	0.0185	0.288	0.0024	0.0024	121
Avg.		13,000	0.222	0.151	0.309	0.0188	0.294	0.0033	0.0024	123
σ		200	0.017	0.013	0.014	0.0028	0.020	0.0008	0.0005	12
22	80/50	11,600	0.311	0.144	0.274	0.00642	0.260	0.0023	0.0022	132
23	80/50	12,600	0.256	0.170	0.287	0.0142	0.267	0.0033	0.0022	137
28	80/50	12,100	0.281	0.131	0.286	0.0131	0.279	0.0027	0.0067	124
Avg.		12,100	0.283	0.148	0.282	0.0112	0.269	0.0028	0.0037	131
σ		500	0.028	0.020	0.007	0.0042	0.010	0.0005	0.0026	7

TABLE C-2c. ULTIMATE ANALYSIS OF COAL AND REFUSE-DERIVED FUEL MIXTURES

EPA test	% Load/ % RDF	Heating value kj/kg fuel	Moisture kg/kg fuel	Ash content kg/kg fuel	Carbon kg/kg fuel	Hydrogen kg/kg fuel	Oxygen kg/kg fuel	Sulfur kg/kg fuel	Chlorine kg/kg fuel
UNIT 5 - FUEL									
4A	60/0	20,900	0.142	0.199	0.482	0.0347	0.0688	0.0738	NT
4B	60/0	20,900	0.142	0.199	0.482	0.0347	0.0688	0.0738	NT
20	60/0	21,500	0.133	0.180	0.512	0.0397	0.0498	0.085	0.00058
21	60/0	20,800	0.150	0.180	0.496	0.0279	0.0933	0.0516	0.00049
36	60/0	20,900	0.119	0.226	0.498	0.0321	0.0634	0.0614	0.00068
Avg.		21,000	0.137	0.197	0.494	0.0338	0.0688	0.0691	0.0058
σ		282.8	0.012	0.019	0.013	0.0043	0.0157	0.0129	0.0010
8	60/20	18,400	0.175	0.178	0.423	0.0264	0.149	0.0475	0.00086
9A	60/20	18,300	0.177	0.176	0.433	0.0267	0.142	0.044	0.00065
9B	60/20	18,300	0.178	0.175	0.425	0.0315	0.146	0.044	0.00065
33	60/20	19,500	0.129	0.188	0.466	0.033	0.130	0.0537	0.00081
Avg.		18,625	0.165	0.179	0.437	0.0294	0.142	0.0473	0.00074
σ		585.2	0.024	0.006	0.020	0.0033	0.008	0.0046	0.00011
1	60/50	16,000	0.162	0.197	0.377	0.0358	0.203	0.0241	0.00125
34	60/50	16,900	0.174	0.157	0.384	0.0247	0.237	0.0217	0.00178
35	60/50	15,100	0.227	0.178	0.359	0.0225	0.198	0.0143	0.00135
Avg.		16,000	0.188	0.177	0.373	0.0277	0.213	0.0200	0.00074
σ		900	0.035	0.020	0.013	0.0071	0.021	0.0051	0.00028
5	80/0	21,600	0.154	0.181	0.498	0.0294	0.0792	0.0591	NT
16	80/0	20,800	0.134	0.200	0.498	0.034	0.0739	0.0596	0.00039
17	80/0	20,800	0.136	0.199	0.496	0.0335	0.0726	0.062	0.00049
Avg.		21,067	0.141	0.193	0.497	0.0323	0.0752	0.0602	0.0004
σ		461.9	0.011	0.011	0.001	0.0025	0.0036	0.0016	0.0001
6	80/20	18,800	0.165	0.198	0.434	0.0317	0.125	0.0459	0.00066
12	80/20	18,100	0.170	0.177	0.412	0.0333	0.168	0.0392	0.00098
13	80/20	18,200	0.158	0.176	0.431	0.035	0.156	0.0422	0.0009
Avg.		18,367	0.164	0.184	0.426	0.0333	0.150	0.0424	0.00085
σ		378.6	0.006	0.012	0.012	0.0017	0.022	0.0034	0.00017
2	80/50	16,200	0.205	0.162	0.366	0.024	0.207	0.0353	0.00135
10	80/50	17,000	0.168	0.177	0.376	0.0281	0.221	0.0282	0.0022
15	80/50	16,600	0.180	0.199	0.403	0.0292	0.158	0.0281	0.00165
Avg.		16,600	0.184	0.179	0.382	0.0271	0.195	0.0305	0.00173
σ		400	0.019	0.019	0.019	0.0027	0.033	0.0041	0.00043

(continued)

TABLE C-2c. (continued)

EPA test	% Load/ % RDF	Heating value kj/kg fuel	Moisture kg/kg fuel	Ash content kg/kg fuel	Carbon kg/kg fuel	Hydrogen kg/kg fuel	Oxygen kg/kg fuel	Sulfur kg/kg fuel	Chlorine kg/kg fuel
11	100/0	21,700	0.132	0.193	0.508	0.0358	0.070	0.0605	0.00126
31	100/0	20,800	0.137	0.194	0.515	0.0345	0.566	0.0618	0.00049
32	100/0	20,800	0.127	0.221	0.496	0.0354	0.0555	0.0651	0.00039
Avg.		21,100	0.132	0.203	0.382	0.0352	0.231	0.0625	0.00071
σ		519.6	0.005	0.016	0.010	0.0007	0.291	0.0024	0.00048
7	100/20	18,300	0.159	0.188	0.459	0.0303	0.113	0.0486	0.0011
14	100/20	18,600	0.161	0.173	0.440	0.030	0.155	0.0398	0.00134
19	100/20	16,800	0.162	0.216	0.420	0.0343	0.129	0.0368	0.00112
Avg.		17,900	0.161	0.192	0.440	0.0315	0.132	0.0417	0.00119
σ		964.4	0.002	0.022	0.020	0.0024	0.021	0.0061	0.00013
3	100/50	15,100	0.240	0.188	0.368	0.0252	0.145	0.032	0.0018
18	100/50	15,800	0.181	0.191	0.382	0.0274	0.186	0.0291	0.00342
Avg.		15,450	0.211	0.190	0.375	0.0263	0.166	0.0306	0.00261
σ		494.9	0.042	0.002	0.010	0.0016	0.029	0.0021	0.00115
UNIT 6 - FUEL									
24	80/0	21,700	0.183	0.113	0.524	0.0361	0.111	0.032	0.00058
29	80/0	21,900	0.181	0.104	0.529	0.0479	0.109	0.0283	0.00049
30	80/0	20,800	0.185	0.124	0.511	0.0366	0.0966	0.0462	0.00049
Avg.		21,467	0.183	0.114	0.521	0.2143	0.106	0.0355	0.00052
σ		585.9	0.002	0.010	0.009	0.0067	0.008	0.0094	0.00005
25	80/20	18,900	0.194	0.120	0.458	0.0294	0.175	0.022	0.00085
26	80/20	19,000	0.200	0.122	0.457	0.0292	0.166	0.0247	0.00215
27	80/20	18,800	0.190	0.139	0.453	0.0297	0.161	0.0254	0.00104
Avg.		18,900	0.195	0.127	0.456	0.0294	0.167	0.0240	0.00135
σ		100	0.005	0.010	0.003	0.0003	0.007	0.0018	0.00070
22	80/50	15,200	0.268	0.131	0.363	0.0185	0.205	0.013	0.00165
23	80/50	15,600	0.226	0.156	0.367	0.0202	0.215	0.0143	0.00172
28	80/50	15,600	0.247	0.119	0.374	0.0217	0.223	0.0109	0.00437
Avg.		15,467	0.247	0.135	0.368	0.0201	0.214	0.0127	0.00258
σ		230.9	0.021	0.019	0.006	0.0016	0.009	0.0017	0.00155

NT = Not tested.

TABLE C-3a. CALCULATION OF ASH IN FUEL (PYRITE AND H_2O OF HYDRATION CORRECTION)

EPA test	% Load/ % RDF	RDF heat input (%)	Coal ash kg ash/ 100 kg fuel	RDF ash kg ash/ 100 kg fuel	Fuel avg. kg ash/ 100 kg fuel	Correction$^{a/}$ kg ash/ 100 kg fuel	Total AWA$^{b/}$ kg ash/ 100 kg fuel
UNIT 5							
4A	60/0	0	19.9	0	19.9	0.149	20.05
4B	60/0	0	19.9	0	19.9	0.149	20.05
20	60/0	0	18.0	0	18.0	0.536	18.54
21	60/0	0	18.0	0	18.0	-0.199	17.801
36	60/0	0	22.6	0	22.6	-0.324	22.28
Avg.		0	19.7	0	19.7	0.0622	19.744
σ		0	1.9	0	1.9	0.338	1.721
8	60/20	22.3	12.52	5.32	17.8	0.0736	17.87
9A	60/20	24.7	13.02	4.63	17.6	-0.016	17.58
9B	60/20	24.8	12.89	4.63	17.5	-0.006	17.49
33	60/20	16.4	16.56	2.26	18.8	-0.0584	18.74
Avg.		22.05	13.75	4.21	17.9	-0.002	17.92
σ		3.94	1.887	1.34	0.6	0.0551	0.57
1	60/50	54.7	7.58	12.15	19.7	-0.0584	19.64
34	60/50	55.6	6.58	9.14	15.7	-0.041	15.66
35	60/50	68.3	4.33	13.46	17.8	-0.046	17.75
Avg.		59.53	6.16	11.58	17.7	-0.049	17.68
σ		7.61	1.66	2.22	2.0	0.009	1.99
5	80/0	0	18.1	0	18.1	-0.041	18.06
16	80/0	0	20.0	0	20.0	-0.171	19.83
17	80/0	0	19.9	0	19.9	-0.111	19.79
Avg.		0	19.3	0	19.3	-0.1077	19.227
σ		0	1.1	0	1.1	0.0651	1.011
6	80/20	22.7	12.86	6.90	19.8	0.0225	19.82
12	80/20	32.3	11.34	8.79	17.7	-0.0058	17.69
13	80/20	28.4	11.62	6.00	17.6	0.0323	17.63
Avg.		27.80	11.94	7.23	18.37	0.0163	18.38
σ		4.83	0.81	1.42	1.24	0.0198	1.25
2	80/50	47.3	8.15	8.03	16.2	0.1368	16.34
10	80/50	49.9	7.61	10.09	17.7	-0.0056	17.69
15	80/50	40.2	8.98	10.97	19.9	-0.089	19.81
Avg.		45.8	8.25	9.70	17.93	0.0141	17.95
σ		5.02	0.69	1.51	1.86	0.1142	1.75

(continued)

TABLE C-3a. (continued)

EPA test	% Load/ % RDF	RDF heat input (%)	Coal ash kg ash/ 100 kg fuel	RDF ash kg ash/ 100 kg fuel	Fuel avg. kg ash/ 100 kg fuel	Correction[a] kg ash/ 100 kg fuel	Total AWA[b] kg ash/ 100 kg fuel
11	100/0	0	19.3	0	19.3	-0.099	19.20
31	100/0	0	19.4	0	19.4	-0.078	19.32
32	100/0	0	22.1	0	22.1	-0.205	21.89
Avg.		0	20.3	0	20.3	-0.127	20.14
σ		0	1.59	0	1.59	0.068	1.52
7	100/20	21.3	14.17	4.649	18.8	-0.035	18.77
14	100/20	27.2	10.60	6.714	17.3	0.062	17.36
19	100/20	30.2	10.94	10.70	21.6	-0.0408	21.56
Avg.		26.23	11.90	7.35	19.23	-0.05	19.23
σ		4.53	1.97	3.08	2.18	0.01	2.14
3	100/50	41.6	9.115	9.643	18.8	-0.024	18.78
18	100/50	45	7.555	11.58	19.1	-0.0404	19.06
Avg.		43.3	8.335	10.61	18.95	-0.03	18.92
σ		2.40	1.103	1.37	0.21	0.01	0.20
UNIT 6							
24	80/0	0	11.3	0	11.3	-0.1333	11.17
29	80/0	0	10.4	0	10.4	-0.148	10.25
30	80/0	0	12.4	0	12.4	0.0975	12.50
Avg.		0	11.4	0	11.4	0.061	11.31
σ		0	1.0	0	1.0	0.138	1.13
25	80/20	20.0	8.096	3.94	12.0	-0.1421	11.86
26	80/20	21.8	7.106	5.131	12.2	-0.0095	12.19
27	80/20	22.0	8.884	4.988	13.9	-0.1152	13.78
Avg.		21.3	8.029	4.686	12.7	-0.0889	12.61
σ		1.1	0.891	0.650	1.0	0.0701	1.03
22	80/50	48.9	3.899	9.202	13.1	-0.034	13.07
23	80/50	55.4	3.975	11.679	15.6	-0.0308	15.57
28	80/50	49.5	3.815	8.072	11.9	-0.0691	11.83
Avg.		51.3	3.896	9.651	13.5	0.0446	13.49
σ		3.6	0.080	1.845	1.9	0.0212	1.91

[a] Correction factors - corrects for pyrite in fuel and water of hydration in fuel ash.

[b] AWA - as weighed ash - laboratory analysis.

TABLE C-3b. ULTIMATE ANALYSIS OF GRATE ASH

EPA test	% Load/ % RDF	Grate ash control				
		Mineral (%)	Carbon (%)	Hydrogen (%)	Sulfur (%)	kg measured ash/ 100 kg fuel
UNIT 5						
4A	60/0	85.83	9.21	0.77	4.19	8.62
4B	60/0	89.41	6.92	0.54	3.13	8.62
20	60/0	83.85	12.25	0.73	3.17	13.82
21	60/0	83.85	12.25	0.73	3.17	13.64
36	60/0	89.16	5.97	1.42	3.45	10.62
Avg.		86.42	9.32	0.84	3.42	11.06
σ		2.74	2.92	0.34	0.45	2.57
8	60/20	84.71	10.9	0.88	3.51	11.71
9A	60/20	88.68	7.32	0.84	3.16	12.97
9B	60/20	89.98	5.99	0.70	3.33	12.97
33	60/20	90.48	5.78	1.02	2.72	13.49
Avg.		88.46	7.50	0.86	3.18	12.79
σ		2.61	2.37	0.13	0.34	0.76
1	60/50	87.78	8.13	0.84	3.25	14.15
34	60/50	89.76	7.25	0.94	2.05	13.75
35	60/50	91.78	5.66	0.93	1.63	14.56
Avg.		89.77	7.01	0.90	2.31	14.15
σ		2.00	1.25	0.06	0.84	0.42
5	80/0	87.12	8.35	0.71	3.82	11.86
16	80/0	87.61	9.69	0.54	2.16	10.94
17	80/0	88.07	8.38	0.76	2.79	11.68
Avg.		87.60	8.81	0.67	2.92	11.49
σ		0.48	0.77	0.12	0.84	0.49
6	80/20	81.05	14.21	1.01	3.73	12.83
12	80/20	84.07	12.23	0.95	2.75	12.29
13	80/20	82.49	12.59	0.79	4.13	12.66
Avg.		82.54	13.01	0.92	3.54	12.59
σ		1.51	1.05	0.11	0.71	0.28
2	80/50	90.31	6.88	0.68	2.13	12.72
10	80/50	88.12	8.03	0.97	2.88	12.32
15	80/50	92.03	5.60	0.66	1.71	11.89
Avg.		90.15	6.84	0.77	2.24	12.31
σ		1.96	1.22	0.17	0.59	00.42

(Continued)

TABLE C-3b. (continued)

EPA test	% Load/ % RDF	Grate ash content				
		Mineral (%)	Carbon (%)	Hydrogen (%)	Sulfur (%)	kg measured ash/ 100 kg fuel
11	100/0	88.53	7.81	0.86	2.80	13.21
31	100/0	88.16	8.06	0.94	2.84	NT
32	100/0	84.05	12.46	0.51	2.98	NT
Avg.		86.91	9.44	0.77	2.87	13.21
σ		2.49	2.62	0.23	0.09	0
7	100/20	84.16	11.30	0.45	4.09	14.14
14	100/20	87.22	8.95	0.70	3.13	13.97
19	100/20	86.49	8.68	0.74	4.09	15.14
Avg.		85.96	9.64	0.63	3.75	14.42
σ		1.60	1.44	0.16	0.54	0.63
3	100/50	87.39	8.99	0.38	3.24	11.62
18	100/50	82.68	13.32	1.01	2.99	11.01
Avg.		85.04	11.16	0.70	3.12	11.32
σ		3.33	3.06	0.45	0.18	0.43
UNIT 6						
24	80/0	89.66	7.50	0.66	2.18	9.66
29	80/0	94.57	2.48	0.94	2.01	5.67
30	80/0	96.20	1.32	0.83	1.65	7.16
Avg.		93.48	3.77	0.81	1.95	7.50
σ		3.40	3.28	0.14	0.27	2.02
25	80/20	95.46	2.56	0.53	1.45	8.73
26	80/20	94.82	2.63	0.68	1.87	8.67
27	80/20	94.09	3.34	0.93	1.64	7.45
Avg.		94.79	2.84	0.71	1.65	8.28
σ		0.69	0.43	0.20	0.21	0.72
22	80/50	96.01	2.54	0.33	1.12	7.29
23	80/50	95.83	2.28	0.59	1.30	8.84
28	80/50	96.43	2.12	0.60	0.85	8.68
Avg.		96.09	2.31	0.51	1.09	8.27
σ		0.31	0.21	0.15	0.23	0.85

NT = Not tested.

TABLE C-3c. ULTIMATE ANALYSIS OF COLLECTOR ASH

EPA test	% Load/ % RDF	Collector ash Mineral (%)	Collector ash Carbon (%)	Collector ash Hydrogen (%)	Collector ash Sulfur (%)	Collector ash kg measured ash/ 100 kg fuel
UNIT 5						
4A	60/0	86.37	11.38	0.61	1.64	2.83
4B	60/0	86.37	11.38	0.61	1.64	2.83
20	60/0	88.90	8.39	0.55	2.16	4.21
21	60/0	88.90	8.39	0.55	2.16	2.94
36	60/0	77.18	20.15	0.82	1.85	5.19
Avg.		85.54	11.94	0.63	1.89	3.60
σ		4.84	4.83	0.11	0.26	1.06
8	60/20	88.52	8.58	0.57	2.33	5.72
9A	60/20	91.53	5.80	0.43	2.24	6.33
9B	60/20	91.53	5.80	0.43	2.24	6.33
33	60/20	88.65	8.71	0.79	1.85	6.58
Avg.		90.06	7.22	0.56	2.17	6.24
σ		1.70	1.64	0.17	0.21	0.37
1	60/50	95.09	3.37	0.51	1.03	3.69
34	60/50	93.95	4.57	0.34	1.14	3.79
35	60/50	96.26	2.16	0.67	0.91	3.64
Avg.		95.10	3.37	0.51	1.03	3.71
σ		1.16	1.21	0.17	0.12	0.08
5	80/0	82.09	15.21	0.63	2.07	7.08
16	80/0	86.47	11.05	0.55	1.93	7.52
17	80/0	84.75	12.67	0.65	1.93	6.57
Avg.		84.44	12.98	0.61	1.98	7.06
σ		2.21	2.10	0.05	0.08	0.48
6	80/20	84.54	12.5	0.41	2.55	6.01
12	80/20	90.17	5.17	0.44	4.22	6.92
13	80/20	90.17	5.17	0.44	4.22	6.17
Avg.		88.29	7.61	0.43	3.66	6.37
σ		3.25	4.23	0.02	0.96	0.49
2	80/50	90.18	7.00	0.85	1.97	4.49
10	80/50	93.48	3.73	0.38	2.41	4.35
15	80/50	82.90	13.7	0.79	2.61	4.86
Avg.		88.85	8.14	0.67	2.33	4.57
σ		5.41	5.08	0.26	0.33	0.26

(continued)

TABLE G-3c. (continued)

EPA test	% Load/ % RDF	Collector ash Mineral (%)	Carbon (%)	Hydrogen (%)	Sulfur (%)	kg measured ash/ 100 kg fuel
11	100/0	85.38	12.16	0.32	2.14	7.39
31	100/0	82.31	15.03	0.59	2.07	NT
32	100/0	70.71	26.71	0.68	1.90	NT
Avg.		79.47	17.97	0.53	2.04	7.39
σ		7.74	7.71	0.19	0.12	0
7	100/20	85.78	11.30	0.59	2.33	2.69
14	100/20	91.56	5.29	0.51	2.64	3.01
19	100/20	86.96	9.62	0.57	2.85	2.89
Avg.		88.10	8.74	0.56	2.61	2.86
σ		3.05	3.10	0.04	0.26	0.16
3	100/50	89.23	7.63	0.90	2.24	2.89
18	100/50	86.90	9.57	0.72	2.81	3.13
Avg.		88.06	8.60	0.81	2.53	3.01
σ		1.65	1.37	0.13	0.40	0.17
UNIT 6						
24	80/0	87.55	10.38	0.42	1.65	4.35
29	80/0	82.36	15.18	0.88	1.58	4.65
30	80/0	84.34	13.24	0.62	1.80	3.69
Avg.		84.75	12.93	0.64	1.68	4.23
σ		2.62	2.41	0.23	0.11	0.49
25	80/20	86.08	9.20	0.73	1.99	5.48
26	80/20	88.04	9.21	0.48	2.22	4.06
27	80/20	87.73	10.11	0.54	1.62	2.22
Avg.		87.97	9.51	0.58	1.94	3.92
σ		0.21	0.52	0.13	0.30	1.63
22	80/50	81.60	15.36	0.69	2.35	3.39
23	80/50	89.52	8.16	0.69	1.63	2.28
28	80/50	90.46	6.98	1.16	1.40	3.07
Avg.		87.19	10.17	0.85	1.79	2.91
σ		4.87	4.54	0.27	0.50	0.57

NT = Not tested.

TABLE C-3d. COMBINED ASH ANALYSIS

EPA test	% Load/ % RDF	Mineral (%)	Carbon (%)	Hydrogen (%)	Sulfur (%)	Heating value ash mj/kg ash	kg controlled emissions/ 100 kg fuel	Total kg measured ash/ 100 kg fuel
UNIT 5								
4A	60/0	86.01	9.94	0.716	3.33	4.69	1.581	13.07
4B	60/0	88.31	8.54	0.565	2.59	3.93	2.077	13.58
20	60/0	85.22	11.2	0.682	2.90	5.03	0.872	18.93
21	60/0	85.37	11.3	0.685	2.92	5.06	1.637	18.27
36	60/0	83.73	12.4	1.15	2.72	6.08	3.636	19.50
Avg.		85.73	10.68	0.760	2.89	4.96	1.961	16.67
σ		1.67	1.48	0.226	0.28	0.78	1.031	3.09
8	60/20	86.05	10.1	0.768	3.08	4.78	0.944	18.47
9A	60/20	89.86	6.69	0.670	2.78	3.47	2.889	22.22
9B	60/20	90.70	5.92	0.601	2.93	3.13	1.139	20.46
33	60/20	89.72	7.00	0.924	2.36	3.90	3.082	23.16
Avg.		89.08	7.43	0.741	2.79	3.82	2.014	21.08
σ		2.07	1.84	0.140	0.31	0.71	1.128	2.07
1	60/50	89.60	6.94	0.758	2.70	3.68	0.835	18.84
34	60/50	91.04	6.43	0.756	1.77	3.42	2.32	11.76
35	60/50	93.16	4.58	0.849	1.41	2.89	2.89	21.11
Avg.		91.27	5.98	0.788	1.96	3.33	2.01	19.90
σ		1.79	1.24	0.053	0.67	0.40	1.06	1.14
5	80/0	85.10	11.1	0.678	3.12	5.01	0.899	19.83
16	80/0	87.10	10.3	0.544	2.06	4.44	0.810	19.29
17	80/0	86.67	10.2	0.713	2.42	4.70	2.26	20.51
Avg.		86.29	10.53	0.645	2.53	4.72	1.32	19.88
σ		1.05	0.49	0.089	0.54	0.29	0.814	0.612
6	80/20	86.14	9.74	0.803	3.32	4.74	0.750	19.64
12	80/20	86.38	9.55	0.756	3.31	4.61	0.601	19.78
13	80/20	85.20	9.97	0.666	4.16	4.70	0.730	19.55
Avg.		85.91	9.75	0.742	3.60	4.68	0.694	19.66
σ		0.62	0.21	0.070	0.49	0.07	0.081	0.116
2	80/50							
10	80/50	90.27	6.91	0.728	2.09	3.57	0.446	17.67
15	80/50	89.65	6.80	0.801	2.75	3.69	0.592	17.28
Avg.		89.13	8.17	0.701	2.00	3.95	0.675	17.42
σ		89.68	7.29	0.743	2.28	3.74	0.571	17.46
		0.57	0.76	0.052	0.41	0.19	0.116	0.199

(continued)

TABLE C-3d. (continued)

EPA test	% Load/ % RDF	Mineral (%)	Carbon (%)	Hydrogen (%)	Sulfur (%)	Heating value ash mj/kg ash	kg controlled emissions/ 100 kg fuel	Total kg measured ash/ 100 kg fuel
11	100/0	87.34	9.46	0.655	2.55	4.37	0.723	21.31
31	100/0	85.44	11.3	0.780	2.48	5.15	3.532	NT
32	100/0	89.51	6.85	1.17	2.47	4.21	4.342	NT
Avg.		87.43	9.20	0.868	2.50	4.58	2.866	21.31
σ		2.04	2.24	0.269	0.04	0.50	1.899	0
7	100/20	84.48	11.3	0.478	3.74	4.84	0.767	17.55
14	100/20	88.11	8.20	0.661	3.03	3.99	0.562	17.55
19	100/20	86.57	8.86	0.708	3.86	4.36	0.608	18.62
Avg.		86.39	9.45	0.616	3.54	4.40	0.646	17.90
σ		1.82	1.63	0.122	0.45	0.43	0.108	0.619
3	100/50	87.80	8.69	0.495	3.02	3.92	0.423	14.90
18	100/50	83.83	12.3	0.935	2.94	5.78	0.731	14.88
Avg.		85.82	10.50	0.715	2.98	4.85	0.577	14.89
σ		2.81	2.55	0.311	0.06	1.32	0.218	0.020
UNIT 6								
24	80/0	88.88	8.57	0.571	1.98	3.89	1.35	15.41
29	80/0	88.38	8.92	0.910	1.79	4.48	1.18	11.51
30	80/0	91.67	5.87	0.750	1.71	3.21	0.724	11.59
Avg.		89.64	7.79	0.744	1.83	3.86	1.08	12.84
σ		1.77	1.67	0.170	0.14	0.64	0.323	2.23
25	80/20	92.33	5.38	0.615	1.68	2.85	0.977	15.17
26	80/20	92.27	5.13	0.604	2.00	2.78	1.26	14.0
27	80/20	91.90	5.67	0.796	1.63	3.20	1.69	11.38
Avg.		92.17	5.39	0.672	1.77	2.94	1.31	13.52
σ		0.23	0.27	0.108	0.20	0.23	0.359	1.94
22	80/50	90.16	7.74	0.476	1.62	3.44	1.58	12.24
23	80/50	93.91	4.07	0.620	1.40	2.39	1.59	12.71
28	80/50	94.47	3.72	0.785	1.03	2.47	1.20	12.95
Avg.		92.85	5.18	0.627	1.35	2.77	1.46	12.63
σ		2.34	2.23	0.155	0.30	0.58	0.221	0.358

NT = Not tested.

TABLE C-4a. CALCULATED BOILER PERFORMANCE DATA

EPA test	% Load	RDF heat (%)	Firing rate of coal (kg/hr)	Heating value of coal (MJ/kg)	Firing rate of RDF (kg/hr)	Heating value of RDF (MJ/kg)	Steam flow (kg/hr)	Heat input Coal (GJ/hr)	Heat input RDF (GJ/hr)	Heat input Fuel (GJ/hr)	Heat input Kj/kg steam generated
UNIT 5											
4A	60	0	4,477	20.9	0	0	25,850	93.57	0	93.57	3,620
4B	60	0	4,477	20.9	0	0	25,850	93.57	0	93.57	3,620
20	60	0	4,238	21.5	0	0	25,620	91.12	0	91.12	3,557
21	60	0	4,293	20.8	0	0	25,620	89.29	0	89.29	3,485
36	60	0	4,490	20.9	0	0	25,400	93.84	0	93.84	3,694
Avg.		0	4,395	21.0	0	0	25,670	92.28	0	92.28	3,595
σ		0	120	0.3	0	0	190	2.00	0	2.00	78.41
8	60	21.7	3,766	21.4	1,875	12.4	25,850	80.59	23.25	103.84	4,017
9A	60	24.1	3,219	21.0	1,678	13.2	25,850	67.60	22.15	89.75	3,472
9B	60	24.2	3,219	20.9	1,678	13.2	25,850	67.28	22.15	89.43	3,460
33	60	16.0	3,557	20.4	889	16.0	25,850	72.56	14.22	86.78	3,357
Avg.		21.5	3,440	20.9	1,530	13.7	25,850	72.01	20.44	92.45	3,577
σ		3.8	269	0.4	437	1.6	0	6.21	4.18	7.71	298.2
1	60	53.9	1,864	21.4	3,617	13.3	26,300	39.89	48.11	88.00	3,346
34	60	54.9	1,926	21.9	3,697	14.3	25,620	42.18	52.87	95.05	3,710
35	60	67.7	1,179	21.6	4,136	13.3	26,080	25.47	55.01	80.48	3,086
Avg.		58.8	1,656	21.6	3,817	13.6	26,000	35.85	52.00	87.84	3,381
σ		7.7	414	0.3	279	0.6	350	9.06	3.53	7.29	313.4
5	80	0	5,388	21.6	0	0	34,470	116.38	0	116.38	3,376
16	80	0	5,718	20.8	0	0	34,690	118.93	0	118.93	3,428
17	80	0	5,357	20.8	0	0	34,920	111.43	0	111.43	3,191
Avg.		0	5,487	21.1	0	0	34,690	115.58	0	115.58	3,332
σ		0	200	0.5	0	0	230	3.81	0	3.81	125.6
6	80	22.2	4,253	21.7	2,103	12.9	34,010	92.29	27.13	119.42	3,511
12	80	31.6	3,601	21.3	2,666	13.7	34,010	76.70	36.52	113.22	3,329
13	80	27.7	3,680	21.4	2,384	13.1	34,920	78.75	31.23	109.98	3,149
Avg.		27.2	3,845	21.5	2,384	13.2	34,320	82.58	31.63	114.21	3,330
σ		4.7	356	0.2	282	0.4	520	8.47	4.71	4.80	181.0
2	80	46.5	2,741	20.7	3,896	13.0	34,470	56.74	50.65	107.39	3,115
10	80	49.2	2,812	21.7	4,366	13.9	34,250	61.02	60.69	121.71	3,554
15	80	39.5	3,236	21.0	3,612	12.7	33,570	67.96	45.87	113.83	3,391
Avg.		45.1	2,930	21.1	3,958	13.2	34,100	61.91	52.40	114.31	3,353
σ		5.0	268	0.5	381	0.6	470	5.66	7.56	7.17	221.9

(continued)

TABLE C-4a. (continued)

EPA test	% Load	RDF heat (%)	Firing rate of coal (kg/hr)	Heating value of coal (MJ/kg)	Firing rate of RDF (kg/hr)	Heating value of RDF (MJ/kg)	Steam flow (kg/hr)	Heat input			Kj/kg steam generated
								Coal (GJ/hr)	RDF (GJ/hr)	Fuel (GJ/hr)	
11	100	0	6,220.6	21.7	0	0	41,960	134.99	0	134.99	3,217
31	100	0	6,972.2	20.8	0	0	42,180	145.02	0	145.02	3,438
32	100	0	6,628.3	20.8	0	0	40,140	137.87	0	137.87	3,435
Avg.		0	6,607.0	21.1	0	0	41,430	139.29	0	139.29	3,363
σ		0	376.3	0.5	0	0	1,120	5.16	0	5.16	126.7
7	100	20.8	5,019.4	20.6	2,174.1	12.9	42,180	103.40	28.05	131.45	3,116
14	100	26.6	4,368.5	22.4	2,830.9	12.9	40,820	97.85	36.52	134.37	3,292
19	100	29.5	4,583.1	21.0	3,617.8	11.5	39,920	96.25	41.60	137.85	3,453
Avg.		25.6	4,657.0	21.3	2,874.4	12.4	40,970	99.17	36.39	134.56	3,287
σ		4.4	331.7	0.9	723.0	0.8	1,140	3.75	6.85	3.20	168.6
3	100	40.9	4,112.7	20.2	5,317.5	11.1	39,920	83.08	59.02	142.10	3,560
18	100	44.3	3,587.9	22.1	5,531.1	11.7	41,740	79.29	64.71	144.00	3,450
Avg.		42.6	3,850.5	21.2	5,424.5	11.4	40,820	81.19	61.87	143.05	3,505
σ		2.4	371.1	1.3	151.1	0.4	1,280	2.68	4.02	1.34	78
UNIT 6											
24	80	0	6,640.1	21.7	0	0	45,590	144.09	0	144.09	3,161
29	80	0	6,607.9	21.9	0	0	44,910	144.71	0	144.71	3,222
30	80	0	6,556.2	20.8	0	0	46,050	136.37	0	136.37	2,961
Avg.		0	6,601.6	21.5	0	0	45,510	141.72	0	141.72	3,115
σ		0	42.3	0.6	0	0	570	4.65	0	4.65	136.5
25	80	19.5	5,684.9	21.2	2,286.6	13.2	45,810	120.52	30.18	150.70	3,290
26	80	21.2	5,569.2	21.7	2,591.8	13.0	46,040	120.85	33.69	154.54	3,357
27	80	21.5	5,364.2	21.6	2,551.0	12.8	44,910	115.87	32.65	148.52	3,307
Avg.		20.7	5,539.3	21.5	2,476.6	13.0	45,590	119.08	32.17	151.25	3,318
σ		1.1	162.4	0.3	165.7	0.2	600	2.78	1.80	3.05	34.83
22	80	47.8	3,356.6	21.6	5,956.6	11.6	44,910	72.50	69.10	141.60	3,153
23	80	54.6	2,727.9	22.2	5,977.0	12.6	44,910	60.56	75.31	135.87	3,025
28	80	49.3	3,848.7	21.7	6,744.9	12.1	44,450	83.52	81.61	165.13	3,715
Avg.		50.6	3,311.2	21.8	6,226.0	12.1	44,760	72.19	75.34	147.53	3,298
σ		3.6	562.0	0.3	449.4	0.5	260	11.48	6.26	15.51	367.0

TABLE C-4b. CALCULATED BOILER PERFORMANCE DATA

EPA test	% Load % RDF	Boiler efficiency Direct (%)	Boiler efficiency Indirect (%)	Boiler efficiency Average (%)	Orsat analysis CO_2 %	Orsat analysis O_2 %	Orsat analysis N_2 %
UNIT 5							
4A	80/0	74.15	75.90	75.03	6.63	9.23	84.14
4B	80/0	74.17	77.37	75.77	7.26	9.31	83.43
20	60/0	74.87	76.89	75.88	8.99	10.37	80.65
21	60/0	76.24	79.44	77.84	9.73	9.61	80.65
36	60/0	74.96	76.97	75.97	8.07	10.72	81.21
Avg.		74.88	77.31	76.10	8.14	9.85	82.02
σ		0.85	1.31	1.04	1.26	0.66	1.65
8	60/21.7	66.51	73.43	69.97	6.56	9.59	83.86
9A	60/24.1	76.77	74.07	75.42	7.02	10.00	82.99
9B	60/24.2	77.11	72.97	75.04	6.46	12.68	80.86
33	60/16.0	81.34	75.84	78.59	7.51	11.26	81.23
Avg.		75.43	74.08	74.76	6.89	10.88	82.24
σ		6.30	1.26	3.56	0.48	1.39	1.43
1	60/53.9	80.42	71.52	75.97	6.56	11.54	81.90
34	60/54.9	74.23	79.53	76.88	7.41	11.16	81.46
35	60/67.7	88.49	75.15	81.82	7.78	11.16	81.01
Avg.		81.05	75.40	78.22	6.89	11.29	81.46
σ		7.15	4.01	3.15	0.63	0.22	0.45
5	80/0	78.90	75.83	77.37	7.35	9.44	83.20
16	80/0	80.19	75.83	78.01	7.55	11.65	80.80
17	80/0	86.48	74.88	80.68	7.24	11.75	81.01
Avg.		81.86	75.51	78.69	7.38	10.95	81.67
σ		4.06	0.55	1.76	0.16	1.31	1.33

(continued)

TABLE C-4b. (continued)

EPA test	% Load % RDF	Boiler efficiency Direct (%)	Boiler efficiency Indirect (%)	Boiler efficiency Average (%)	Orsat analysis CO_2 %	Orsat analysis O_2 %	Orsat analysis N_2 %
6	80/22.2	75.24	74.42	74.83	7.72	10.39	82.43
12	80/31.6	79.81	74.91	77.36	8.36	10.24	81.40
13	80/27.7	84.33	75.02	79.68	8.96	9.62	81.42
Avg.		79.79	74.78	77.29	8.35	10.08	81.75
σ		4.55	0.32	2.43	0.62	0.41	0.59
2	80/46.5	85.35	76.50	80.93	8.70	9.40	81.90
10	80/49.2	75.62	76.68	76.15	8.47	9.69	81.83
15	80/39.5	80.82	74.08	77.45	7.72	10.14	82.15
Avg.		80.60	75.75	78.18	8.30	9.74	81.96
σ		4.87	1.45	2.47	0.51	0.37	0.17
11	100/0	81.62	80.12	80.87	11.53	6.74	81.74
31	100/0	79.02	78.24	78.63	11.06	7.01	81.92
32	100/0	78.64	77.82	78.23	9.78	9.12	81.10
Avg.		79.76	78.73	79.24	10.79	7.62	81.59
σ		1.62	1.22	1.42	0.91	1.30	0.43
7	100/20.8	83.52	75.34	79.43	9.10	8.23	82.67
14	100/26.6	83.79	78.50	81.15	9.78	8.41	81.81
19	100/29.5	77.73	77.00	77.37	11.08	7.11	81.81
Avg.		81.68	76.95	79.32	9.99	7.92	82.10
σ		3.42	1.58	1.89	1.01	0.70	0.50
3	100/40.9	74.42	72.02	73.22	7.95	8.85	83.20
18	100/44.3	79.19	76.07	77.63	10.07	8.85	81.08
Avg.		76.81	74.05	75.43	9.01	8.85	82.14
σ		3.37	2.86	3.12	1.50	0.0	1.50

(continued)

TABLE C-4b. (continued)

EPA test	% Load %RDF	Boiler efficiency Direct (%)	Boiler efficiency Indirect (%)	Boiler efficiency Average (%)	Orsat analysis CO_2 %	Orsat analysis O_2 %	Orsat analysis N_2 %
UNIT 6							
24	80/0	82.42	78.89	80.66	8.90	10.04	81.05
29	80/0	80.94	77.80	79.37	8.63	9.31	82.06
30	80/0	87.88	82.79	85.34	11.90	6.27	81.83
Avg.		83.75	79.83	81.79	9.81	8.54	81.65
σ		3.66	2.62	3.14	1.82	2.00	0.53
25	80/19.5	79.58	78.51	79.05	8.88	10.01	81.11
26	80/21.2	77.47	78.40	77.94	8.52	10.45	81.03
27	80/21.5	78.88	79.34	79.11	9.09	8.90	82.01
Avg.		78.64	78.75	78.70	8.83	9.79	81.39
σ		1.07	0.51	0.66	0.29	0.80	0.54
22	80/47.8	82.37	79.10	80.74	9.69	8.82	82.09
23	80/54.6	85.96	79.15	82.56	9.21	9.80	80.99
28	80/49.3	70.23	77.92	74.08	8.51	9.82	81.67
Avg.		79.52	78.72	79.13	9.14	9.48	81.58
σ		8.24	0.70	4.46	0.59	0.57	0.56

TABLE C-4c. CALCULATED BOILER PERFORMANCE DATA

EPA test	% Load % RDF	% Excess Air			Calculated orsat		
		By N_2 balance	By O_2 balance	Corrected	CO_2 %	O_2 %	N_2 %
UNIT 5							
4A	60/0	183.79	114.94	166.44	6.35	13.43	79.86
4B	60/0	158.01	106.65	144.80	6.94	12.72	79.95
20	60/0	92.53	89.81	91.46	8.50	10.58	80.41
21	60/0	92.14	82.07	89.31	9.43	10.46	79.77
36	60/0	122.89	105.88	117.90	7.78	11.96	79.91
Avg.		129.87	99.87	121.98	7.80	11.83	79.98
σ		40.51	13.48	33.57	1.22	1.30	0.25
8	60/21.7	207.62	127.60	188.62	6.36	14.11	79.28
9A	60/24.1	185.21	125.37	171.68	6.81	13.63	79.33
9B	60/24.2	195.21	171.00	189.69	6.25	14.06	79.47
33	60/16.0	150.43	126.66	145.12	7.23	12.87	79.61
Avg.		184.62	137.66	173.78	6.66	13.67	79.42
σ		24.57	22.25	20.81	0.45	0.57	0.15
1	60/53.9	194.62	151.92	184.09	6.47	13.99	79.40
34	60/54.9	192.57	146.25	182.32	7.29	13.85	78.72
35	60/67.7	173.61	137.54	165.66	7.70	13.40	78.81
Avg.		186.93	145.24	177.36	7.15	13.75	78.98
σ		11.58	7.24	10.17	0.63	0.31	0.37
5	80/0	157.49	105.73	145.21	7.10	12.91	79.69
16	80/0	138.63	125.94	135.11	7.26	12.52	79.91
17	80/0	148.89	131.93	144.52	6.96	12.88	79.85
Avg.		148.34	121.20	141.61	7.11	12.77	79.82
σ		9.44	13.73	5.64	0.15	0.22	0.11

(continued)

TABLE C-4c. (continued)

EPA test	% Load % RDF	% Excess air			Calculated orsat		
		By N_2 balance	By O_2 balance	Corrected	CO_2 %	O_2 %	N_2 %
6	80/22.2	144.04	111.05	135.79	7.45	12.61	79.67
12	80/31.6	126.23	102.02	120.42	8.13	12.04	79.58
13	80/27.7	107.60	87.45	102.66	8.72	11.25	79.76
Avg.		125.96	100.17	119.62	8.10	11.97	79.67
σ		18.22	11.91	16.58	0.64	0.68	0.09
2	80/46.5	144.88	101.71	134.71	8.45	12.40	78.87
10	80/49.2	146.64	105.79	136.59	8.32	12.49	78.99
15	80/39.5	154.69	114.25	144.39	7.60	12.81	79.41
Avg.		148.74	107.25	138.56	8.12	12.57	79.09
σ		5.23	6.40	5.13	0.46	0.22	0.28
11	100/0	56.47	44.85	53.54	11.10	7.97	80.46
31	100/0	61.32	46.97	58.02	10.63	8.52	80.40
32	100/0	81.82	72.80	79.76	9.36	9.95	80.25
Avg.		66.54	54.87	63.77	10.36	8.81	80.37
σ		13.46	15.56	14.02	0.90	1.02	0.11
7	100/20.8	108.78	74.05	99.97	8.86	11.04	79.78
14	100/26.6	100.15	73.84	93.63	9.55	10.61	79.55
19	100/29.5	66.60	50.21	61.73	10.88	8.69	80.13
Avg.		91.84	66.03	85.11	9.76	10.11	79.82
σ		22.28	13.70	20.49	1.03	1.25	0.29
3	100/40.9	152.87	97.42	138.70	7.81	12.59	79.37
18	100/44.3	96.60	75.09	90.06	9.93	10.60	79.22
Avg.		124.74	86.26	114.38	8.87	11.60	79.30
σ		39.79	15.79	34.39	1.50	1.41	0.11

(continued)

TABLE C-4c. (continued)

EPA test	% Load % RDF	% Excess air			Calculated orsat		
		By N_2 balance	By O_2 balance	Corrected	CO_2 %	O_2 %	N_2 %
UNIT 6							
24	80/0	109.35	95.11	106.34	8.72	11.20	79.90
29	80/0	107.79	86.75	102.85	8.49	11.03	80.32
30	80/0	58.06	44.37	54.54	11.57	7.70	80.35
Avg.		91.73	75.41	87.91	9.59	9.98	80.19
σ		29.17	27.20	28.95	1.72	1.97	0.25
25	80/1.95	126.86	103.19	121.70	8.74	11.78	79.33
26	80/21.2	135.57	112.46	130.29	8.38	12.11	79.36
27	80/21.5	122.26	89.06	113.91	8.97	11.41	79.44
Avg.		128.23	101.57	121.97	8.70	11.77	79.38
σ		6.76	11.78	8.19	0.30	0.35	0.06
22	80/47.8	132.28	90.69	122.09	9.58	11.78	78.53
23	80/54.6	142.90	108.49	133.98	9.16	12.15	78.58
28	80/49.3	164.27	117.36	153.39	8.46	12.83	78.62
Avg.		146.48	105.51	136.49	9.07	12.25	78.58
σ		16.29	13.58	15.80	0.57	0.53	0.05

TABLE C-5a. BOILER OPERATING DATA

EPA test	% Load/ % RDF	Steam flow (kg/hr)	Coal (kg/hr)	RDF (kg/hr)	Total (kg/hr)	Steam temp. (°C)	Steam pressure (MPa)	Air in (°C)
UNIT 5								
4A	60/0	25,900	4,480	0	4,480	449	4.15	33
4B	60/0	25,900	4,480	0	4,480	449	4.15	33
20	60/0	25,600	4,240	0	4,480	439	4.21	30
21	60/0	25,600	4,290	0	4,480	440	4.22	32
36	60/0	25,600	4,490	0	4,480	435	4.24	36
Avg.		25,700	4,400	0	4,480	442	4.19	33
σ		164	120	0	0	6	0.04	2
8	60/20	25,900	3,770	1,880	5,650	444	4.21	34
9A	60/20	25,900	3,220	1,680	4,900	438	4.17	30
9B	60/20	25,900	3,220	1,680	4,900	438	4.16	31
33	60/20	25,900	3,560	890	4,450	435	4.22	35
Avg.		25,900	3,440	1,533	4,980	439	4.19	32
σ		0	270	440	500	4	0.03	2
1	60/50	26,300	1,860	3,620	5,480	442	4.18	35
34	60/50	25,600	1,930	3,770	5,620	449	4.25	34
35	60/50	26,100	1,180	4,140	5,320	449	4.33	37
Avg.		26,000	1,660	3,840	5,470	447	4.25	35
σ		361	410	270	150	4	0.08	2
5	80/0	34,500	5,390	0	5,390	457	4.15	32
16	80/0	34,700	5,720	0	5,720	453	4.20	34
17	80/0	34,900	5,360	0	5,360	457	4.22	37
Avg.		34,700	5,490	0	5,490	456	4.19	34
σ		200	200	0	200	2	0.04	3

(continued)

TABLE C-5a. (continued)

EPA test	% Load/ % RDF	Steam flow (kg/hr)	Coal (kg/hr)	RDF (kg/hr)	Total (kg/hr)	Steam temp. (°C)	Steam pressure (MPa)	Air in (°C)
6	80/20	34,000	4,250	2,100	6,350	446	4.12	31
12	80/20	34,000	3,600	2,670	6,270	452	4.19	33
13	80/20	34,900	3,680	2,380	6,060	450	4.21	35
Avg.		34,300	3,840	2,380	6,230	449	4.17	33
σ		520	350	290	150	3	0.05	2
2	80/50	34,500	2,740	3,900	6,640	455	4.17	32
10	80/50	34,200	2,810	4,370	7,180	460	4.16	30
15	80/50	33,600	3,240	3,610	6,850	451	4.21	34
Avg.		34,100	2,930	3,960	6,890	455	4.18	32
σ		458	270	380	270	5	0.03	2
11	100/0	42,000	6,220	0	6,220	442	4.25	34
31	100/0	42,000	6,970	0	6,970	456	4.21	37
32	100/0	40,100	6,630	0	6,630	444	4.22	35
Avg.		41,400	6,610	0	6,610	447	4.23	35
σ		1,200	380	0	380	8	0.02	2
7	100/20	42,200	5,020	2,170	7,190	439	4.23	32
14	100/20	40,800	4,370	2,830	7,200	454	4.19	35
19	100/20	39,900	4,580	3,620	8,200	433	4.18	34
Avg.		41,000	4,660	2,870	7,530	442	4.20	34
σ		1,200	330	730	580	11	0.03	2
3	100/50	39,900	4,110	5,320	9,430	464	4.20	30
18	100/50	41,700	3,590	5,530	9,120	456	4.23	37
Avg.		40,800	3,850	5,420	9,270	460	4.22	34
σ		1,300	370	148	219	6	0.02	5

(continued)

TABLE C-5a. (continued)

EPA test	% Load/ % RDF	Steam flow (kg/hr)	Coal (kg/hr)	RDF (kg/hr)	Total (kg/hr)	Steam temp. (°C)	Steam pressure (MPa)	Air in (°C)
UNIT 6								
24	80/0	45,600	6,640	0	6,640	446	4.40	38
29	80/0	44,900	6,610	0	6,610	448	4.45	39
30	80/0	46,000	6,560	0	6,560	445	4.50	44
Avg.		45,500	6,600	0	6,600	446	4.45	41
σ		600	30	0	40	2	0.05	3
25	80/20	45,800	5,690	2,290	7,980	449	4.45	37
26	80/20	46,000	5,570	2,590	8,160	446	4.48	42
27	80/20	44,900	5,360	2,550	7,910	448	4.45	40
Avg.		45,600	5,540	2,480	8,020	447	4.46	40
σ		600	167	163	129	2	0.02	3
22	80/50	44,900	3,360	5,960	9,320	444	4.53	41
23	80/50	44,900	2,730	5,980	8,710	445	4.45	38
28	80/50	44,500	3,850	6,740	10,600	447	4.44	41
Avg.		44,800	3,310	6,230	9,540	445	4.47	40
σ		200	561	445	965	2	0.05	2

TABLE C-5b. BOILER OPERATING DATA

EPA test	Water to economizer (°C)	Water from economizer (°C)	Flue gas to economizer (°C)	Flue gas from economizer (°C)	Particulate collector (°C)	To stack (°C)	Wet bulb (°C)	Dry bulb (°C)	Specific humidity kg H_2O/kg DA[a]
UNIT 5									
4A	152	204	279	195	194	172	20	32	0.0114
4B	152	194	278	200	195	170	20	32	0.0114
20	151	184	285	200	199	169	17	20	0.0106
21	153	144	285	192	196	170	18	24	0.0103
36	129	180	283	198	191	174	21	31	0.0109
Avg.	147	181	282	197	195	171	19	28	0.0109
σ	10	23	3	4	3	2	2	6	0.0005
8	152	205	287	210	206	194	18	31	0.0074
9A	150	211	290	212	205	189	13	18	0.0074
9B	149	205	288	210	206	191	16	24	0.0074
33	134	183	291	200	194	167	23	31	0.0104
Avg.	146	202	289	208	203	185	17	26	0.0082
σ	8	10	2	5	6	12	4	6	0.0015
1	147	197	286	206	206	179	21	30	0.0120
34	135	192	297	201	199	171	22	30	0.0137
35	135	194	303	203	201	174	23	28	0.0151
Avg.	139	193	295	203	202	175	22	29	0.0136
σ	7	3	9	3	4	4	1	1	0.0016
5	159	199	293	214	208	189	18	30	0.0073
16	138	184	300	205	204	174	21	27	0.0134
17	139	182	285	202	205	171	24	31	0.0160
Avg.	146	188	293	207	206	178	21	29	0.0104
σ	12	9	8	6	2	10	3	2	0.0043
6	159	203	295	217	212	192	17	25	0.0086
12	158	200	299	220	214	203	21	29	0.0124
13	157	201	303	224	218	200	23	33	0.0140
Avg.	158	201	299	220	215	198	20	29	0.0117
σ	1	2	4	4	3	6	3	4	0.0028
2	159	205	308	215	213	190	21	28	0.0130
10	156	202	297	218	216	201	16	24	0.0077
15	140	186	296	215	211	181	20	35	0.0083
Avg.	152	197	300	216	213	191	19	29	0.0097
σ	10	10	7	2	3	10	3	6	0.0029

(continued)

TABLE C-5b. (continued)

EPA test	Water to economizer (°C)	Water from economizer (°C)	Flue gas to economizer (°C)	Flue gas from economizer (°C)	Particulate collector (°C)	To stack (°C)	Wet bulb (°C)	Dry bulb (°C)	Specific humidity kg H_2O/kg DA
11	161	195	295	217	213	197	20	29	0.0111
31	147	192	306	207	204	199	19	23	0.0127
32	145	189	304	206	205	196	23	28	0.0163
Avg.	151	192	302	210	207	197	21	27	0.0134
σ	9	3	6	6	5	2	2	3	0.0027
7	164	201	299	218	218	202	20	31	0.0100
14	138	186	309	216	213	189	18	31	0.0073
19	144	177	299	210	209	192	20	26	0.0124
Avg.	149	188	302	215	213	194	19	29	0.0099
σ	14	12	6	5	5	7	1	3	0.0026
3	167	204	311	226	223	193	-	23	0.0119
18	143	182	306	209	213	199	-	28	0.0180
Avg.	155	193	308	218	218	196	-	26	0.0150
σ	17	16	4	12	7	4	-	4	0.0043
UNIT 6									
24	169	230	321	205	205	190	19	23	0.0106
29	169	229	320	204	205	189	16	19	0.0096
30	167	216	306	194	195	188	26	30	0.0187
Avg.	168	225	316	201	202	189	20	24	0.0148
σ	1	8	8	6	6	1	5	6	0.0047
25	167	230	321	205	209	183	23	29	0.0159
26	167	230	321	206	211	180	26	30	0.0189
27	167	231	321	204	209	180	24	30	0.0170
Avg.	167	231	321	205	210	181	24	30	0.0173
σ	0	1	0	1	1	2	2	1	0.0015
22	166	233	323	206	199	198	23	30	0.0131
23	167	232	323	205	211	195	18	23	0.0111
28	165	232	322	201	207	205	21	30	0.0119
Avg.	166	232	323	204	206	199	21	28	0.0120
σ	1	1	1	3	6	5	3	4	0.0010

a/ Dry air

APPENDIX D - CHARACTERISTICS OF ASH AND OTHER RELATED PROPERTIES

TABLE D-1. ASH FUSION TEMPERATURES (°C) FOR COAL, RDF, GRATE, AND COLLECTOR ASH

EPA	RDF Heat, %	Sample	Reducing atmosphere				Oxidizing atmosphere			
			IT	ST	HT	FT	IT	ST	HT	FT
UNIT 5										
60% Load 0% RDF										
4A and B	0.0	Coal	1193	1232	1243	1254	1260	1282	1304	1343
		Refuse	-	-	-	-	-	-	-	-
		Grate ash	1160	1193	1210	1227	1227	1254	1266	1299
		Coll. ash	1049	1054	1060	1066	1188	1193	1199	1204
20	0.0	Coal	1127	1132	1138	1143	1249	1254	1260	1266
		Refuse	-	-	-	-	-	-	-	-
		Grate ash	1077	1093	1099	1116	1238	1249	1260	1282
		Coll. ash	1116	1121	1127	1143	1227	1232	1238	1271
21	0.0	Coal	1121	1132	1143	1154	1210	1216	1221	1227
		Refuse	-	-	-	-	-	-	-	-
		Grate ash	1071	1077	1082	1093	1238	1249	1254	1266
		Coll. ash	1104	1116	1127	1138	1243	1249	1254	1277
36	0.0	Coal	1177	1179	1182	1185	1213	1216	1218	1221
		Refuse	-	-	-	-	-	-	-	-
		Grate ash	1188	1193	1216	1238	1227	1232	1238	1243
		Coll. ash	1116	1127	1132	1149	1221	1232	1238	1243
60% Load 20% RDF										
8	21.9	Coal	1199	1221	1227	1232	1238	1243	1249	1260
		Refuse	1110	1149	1171	1232	1138	1154	1177	1249
		Grate ash	1143	1154	1160	1166	1221	1232	1238	1243
		Coll. ash	1099	1104	1116	1121	1182	1188	1199	1204
9A	23.2	Coal	1193	1221	1227	1238	1232	1243	1249	1254
		Refuse	1088	1127	1160	1210	1127	1143	1166	1243
		Grate ash	1132	1149	1160	1171	1193	1204	1216	1227
		Coll. ash	1088	1093	1104	1110	1160	1166	1171	1182
9B	23.3	Coal	1149	1188	1199	1210	1243	1260	1266	1282
		Refuse	1088	1127	1160	1210	1127	1143	1166	1243
		Grate ash	1149	1154	1160	1171	1199	1210	1221	1232
		Coll. ash	1088	1093	1104	1110	1160	1166	1171	1182
33	16.0	Coal	1232	1238	1243	1249	1238	1243	1249	1254
		Refuse	1110	1121	1132	1149	1143	1154	1166	1182
		Grate ash	1149	1160	1171	1177	1193	1199	1204	1210
		Coll. ash	1093	1099	1104	1110	1149	1154	1160	1166

(continued)

TABLE D-1. (continued)

EPA	RDF Heat, %	Sample	Reducing atmosphere IT	Reducing atmosphere ST	Reducing atmosphere HT	Reducing atmosphere FT	Oxidizing atmosphere IT	Oxidizing atmosphere ST	Oxidizing atmosphere HT	Oxidizing atmosphere FT
60% Load 50% RDF										
1	53.9	Coal	1143	1149	1152	1154	1243	1246	1249	1252
		Refuse	1116	1154	1177	1210	1138	1166	1182	1210
		Grate ash	1066	1082	1088	1110	1154	1171	1182	1204
		Coll. ash	NT	NT	NT	NT	NT	NT	NT	NT
34	54.9	Coal	1227	1232	1238	1243	1243	1249	1254	1260
		Refuse	1138	1149	1166	1188	1154	1160	1177	1216
		Grate ash	1127	1132	1138	1143	1166	1171	1177	1182
		Coll. ash	1127	1135	1143	1149	1177	1188	1199	1210
35	69.3	Coal	1177	1182	1188	1199	1216	1221	1227	1232
		Refuse	NT	NT	NT	NT	NT	NT	NT	NT
		Grate ash	1138	1143	1149	1160	1171	1177	1182	1188
		Coll. ash	1138	1149	1166	1177	1182	1188	1199	1216
80% Load 0% RDF										
5	0.0	Coal	1149	1199	1210	1221	1266	1277	1282	1299
		Refuse	-	-	-	-	-	-	-	-
		Grate ash	1154	1182	1193	1221	1199	1227	1238	1249
		Coll. ash	1071	1077	1082	1088	1199	1204	1210	1216
16	0.0	Coal	1171	1177	1182	1188	1238	1249	1254	1260
		Refuse	-	-	-	-	-	-	-	-
		Grate ash	1060	1071	1077	1082	1204	1221	1232	1249
		Coll. ash	1227	1138	1149	1154	1182	1196	1210	1227
17	0.0	Coal	1116	1118	1121	1124	1227	1232	1238	1246
		Refuse	-	-	-	-	-	-	-	-
		Grate ash	1060	1066	1071	1077	1232	1238	1243	1254
		Coll. ash	1066	1082	1088	1110	1193	1227	1260	1271

(continued)

TABLE D-1. (continued)

EPA	RDF Heat, %	Sample	Reducing atmosphere				Oxidizing atmosphere			
			IT	ST	HT	FT	IT	ST	HT	FT
80% Load 20% RDF										
6	22.2	Coal	1204	1243	1254	1266	1243	1260	1271	1288
		Refuse	1121	1160	1171	1227	1160	1177	1193	1266
		Grate ash	1121	1138	1149	1154	1199	1210	1216	1221
		Coll. ash	1138	1143	1149	1160	1188	1199	1210	1227
12	31.6	Coal	1249	1288	1310	1332	1254	1288	1310	1332
		Refuse	1060	1160	1177	1210	1149	1171	1193	1243
		Grate ash	1110	1121	1127	1132	1171	1182	1193	1199
		Coll. ash	1104	1132	1143	1171	1177	1188	1199	1227
13	27.7	Coal	1199	1221	1227	1238	1232	1243	1249	1260
		Refuse	1104	1154	1182	1243	1160	1188	1204	1260
		Grate ash	1116	1121	1127	1132	1188	1210	1221	1227
		Coll. ash	1110	1116	1121	1127	1182	1188	1193	1199
80% Load 50% RDF										
2	46.5	Coal	1093	1104	1110	1121	1254	1293	1338	1371
		Refuse	1077	1138	1160	1221	1132	1149	1166	1254
		Grate ash	1071	1082	1088	1116	1149	1177	1193	1243
		Coll. ash	1088	1116	1143	1171	1171	1182	1193	1204
10	49.2	Coal	1154	1157	1160	1163	1249	1252	1254	1257
		Refuse	1110	1154	1171	1210	1132	1166	1177	1216
		Grate ash	1071	1088	1099	1138	1121	1138	1149	1171
		Coll. ash	1088	1104	1121	1160	1132	1154	1171	1199
15	39.5	Coal	1149	1154	1160	1166	1260	1266	1271	1277
		Refuse	1110	1132	1160	1221	1143	1160	1188	1249
		Grate ash	1088	1104	1116	1127	1127	1160	1177	1238
		Coll. ash	1082	1110	1127	1160	1149	1171	1193	1249

(continued)

TABLE D-1. (continued)

EPA	RDF Heat, %	Sample	Reducing atmosphere				Oxidizing atmosphere			
			IT	ST	HT	FT	IT	ST	HT	FT
100% Load 0% RDF										
11	0.0	Coal	1177	1179	1182	1185	1279	1282	1285	1288
		Refuse	-	-	-	-	-	-	-	-
		Grate ash	1138	1149	1154	1160	1188	1210	1221	1227
		Coll. ash	1071	1082	1088	1093	1193	1204	1210	1216
31	0.0	Coal	1149	1160	1171	1177	1254	1260	1271	1277
		Refuse	-	-	-	-	-	-	-	-
		Grate ash	1093	1099	1110	1118	1227	1238	1249	1260
		Coll. ash	1132	1143	1152	1160	1204	1216	1227	1254
32	0.0	Coal	1127	1129	1132	1135	1182	1185	1188	1191
		Refuse	-	-	-	-	-	-	-	-
		Grate ash	1171	1177	1182	1191	1227	1232	1238	1249
		Coll. ash	1116	1127	1138	1149	1221	1232	1243	1249
100% Load 20% RDF										
7	20.3	Coal	1204	1232	1243	1254	1238	1243	1249	1260
		Refuse	1116	1149	1177	1216	1160	1171	1182	1221
		Grate ash	1093	1110	1121	1132	1193	1204	1232	1243
		Coll. ash	1132	1138	1143	1154	1193	1199	1204	1216
14	26.6	Coal	1168	1171	1174	1177	1277	1279	1282	1285
		Refuse	1099	1160	1182	1238	1171	1193	1204	1249
		Grate ash	1082	1099	1110	1121	1182	1210	1221	1243
		Coll. ash	1088	1121	1132	1171	1171	1188	1204	1232
19	29.5	Coal	1163	1166	1168	1171	1232	1235	1238	1241
		Refuse	1138	1143	1149	1154	1166	1171	1177	1182
		Grate ash	1104	1116	1127	1149	1193	1221	1232	1254
		Coll. ash	1110	1116	1121	1127	1188	1193	1199	1204

(continued)

TABLE D-1. (continued)

EPA	RDF Heat, %	Sample	Reducing atmosphere				Oxidizing atmosphere			
			IT	ST	HT	FT	IT	ST	HT	FT
100% Load 50% RDF										
3	40.9	Coal	1110	1154	1166	1177	1243	1249	1254	1293
		Refuse	1066	1154	1177	1238	1132	1166	1193	1260
		Grate ash	1077	1088	1093	1132	1171	1188	1204	1238
		Coll. ash	1060	1088	1127	1154	1166	1182	1188	1199
18	44.3	Coal	1149	1160	1166	1171	1227	1229	1232	1235
		Refuse	1066	1143	1160	1199	1138	1160	1177	1204
		Grate ash	1082	1104	1121	1154	1143	1171	1182	1193
		Coll. ash	1099	1104	1110	1116	1149	1154	1160	1166
UNIT 6										
80% Load 0% RDF										
24	0.0	Coal	1127	1132	1138	1143	1204	1210	1216	1221
		Refuse	-	-	-	-	-	-	-	-
		Grate ash	1088	1099	1110	1121	1227	1232	1238	1243
		Coll. ash	1093	1099	1104	1110	1188	1193	1199	1210
29	0.0	Coal	1160	1166	1167	1171	1260	1266	1271	1277
		Refuse	-	-	-	-	-	-	-	-
		Grate ash	1082	1093	1104	1116	1249	1254	1260	1263
		Coll. ash	1132	1138	1143	1149	1243	1249	1254	1260
30	0.0	Coal	1143	1146	1149	1152	1246	1249	1252	1254
		Refuse	-	-	-	-	-	-	-	-
		Grate ash	1077	1082	1088	1093	1243	1252	1254	1266
		Coll. ash	1121	1127	1132	1138	1204	1221	1232	1249

(continued)

TABLE D-1. (continued)

EPA	RDF Heat, %	Sample	Reducing atmosphere				Oxidizing atmosphere			
			IT	ST	HT	FT	IT	ST	HT	FT
80% Load 20% RDF										
25	19.5	Coal	1193	1199	1204	1210	1227	1232	1238	1243
		Refuse	1116	1127	1138	1149	1149	1160	1171	1182
		Grate ash	1110	1121	1138	1177	1193	1204	1216	1227
		Coll. ash	1099	1104	1116	1127	1182	1193	1204	1216
26	21.2	Coal	1166	1171	1174	1177	1241	1243	1246	1249
		Refuse	1104	1116	1132	1160	1154	1160	1171	1193
		Grate ash	1071	1088	1099	1149	1177	1193	1216	1221
		Coll. ash	1116	1127	1138	1149	1221	1227	1232	1249
27	21.5	Coal	1160	1166	1171	1174	1218	1221	1224	1227
		Refuse	1121	1127	1132	1154	1160	1171	1177	1204
		Grate ash	1071	1082	1093	1104	1193	1199	1204	1210
		Coll. ash	1121	1132	1143	1154	1216	1227	1238	1254
80% Load 50% RDF										
22	47.8	Coal	1132	1138	1143	1149	1204	1210	1216	1221
		Refuse	1038	1138	1154	1193	1116	1149	1166	1210
		Grate ash	1066	1104	1138	1177	1116	1143	1166	1199
		Coll. ash	1082	1093	1104	1116	1210	1216	1221	1227
23	54.6	Coal	1152	1154	1157	1160	1224	1227	1229	1232
		Refuse	1149	1154	1160	1166	1154	1160	1171	1182
		Grate ash	1004	1099	1116	1149	1110	1121	1149	1166
		Coll. ash	1099	1104	1116	1127	1149	1160	1171	1182
28	32.2	Coal	1160	1163	1166	1171	1229	1232	1235	1238
		Refuse	1093	1104	1116	1127	1149	1160	1182	1193
		Grate ash	1110	1127	1149	1166	1188	1193	1204	1216
		Coll. ash	1127	1132	1138	1143	1188	1193	1204	1216

IT = Initial deformation temperature.

ST = Softening temperature.

HT = Hemispherical temperature.

FT = Fluid temperature.

NT = Not taken.

TABLE D-2. AVERAGE ASH FUSION TEMPERATURES (°C) FOR COAL, RDF, GRATE, AND COLLECTOR ASH

Test	Sample		Reducing atmosphere				Oxidizing atmosphere			
			IT	ST	HT	FT	IT	ST	HT	FT
UNIT 5 - 60% Load										
0% RDF	Coal	Avg.	1155	1169	1177	1184	1233	1242	1251	1264
		σ	36	48	49	50	25	32	40	56
4A, 4B, 20, 21, 36	Refuse	Avg.	-	-	-	-	-	-	-	-
		σ	-	-	-	-	-	-	-	-
	Grate ash	Avg.	1124	1139	1152	1166	1233	1246	1255	1273
		σ	59	63	71	71	6	10	12	24
	Coll. ash	Avg.	1096	1105	1112	1124	1220	1227	1232	1249
		σ	32	34	34	39	23	24	23	33
20% RDF	Coal	Avg.	1193	1217	1224	1232	1238	1247	1253	1263
		σ	34	21	18	16	5	9	9	13
8, 9A, 9B, 33	Refuse	Avg.	1099	1131	1156	1200	1134	1149	1169	1229
		σ	13	12	17	36	8	6	6	32
	Grate ash	Avg.	1143	1154	1163	1171	1202	1211	1220	1228
		σ	8	5	6	5	13	15	14	14
	Coll. ash	Avg.	1092	1097	1107	1113	1164	1167	1175	1184
		σ	5	5	6	6	14	12	17	16
50% RDF	Coal	Avg.	1182	1188	1193	1199	1234	1239	1243	1248
		σ	42	42	43	45	16	15	14	14
1, 34, 35	Refuse	Avg.	1127	1152	1172	1199	1144	1163	1180	1213
		σ	16	4	8	16	15	4	4	4
	Grate ash	Avg.	1110	1119	1125	1138	1164	1173	1180	1191
		σ	39	33	33	25	9	3	3	11
	Coll. ash	Avg.	1132	1142	1155	1163	1180	1188	1199	1213
		σ	8	10	16	20	4	0	0	4
80% Load										
0% RDF	Coal	Avg.	1145	1165	1171	1178	1244	1253	1258	1268
		σ	28	42	46	49	20	23	22	27
5, 16, 17	Refuse	Avg.	-	-	-	-	-	-	-	-
		σ	-	-	-	-	-	-	-	-
	Grate ash	Avg.	1091	1106	1114	1127	1212	1229	1238	1251
		σ	54	66	69	82	18	9	6	3
	Coll. ash.	Avg.	1088	1099	1106	1117	1191	1209	1227	1238
		σ	34	34	37	34	9	16	29	29
20% RDF	Coal	Avg.	1217	1251	1264	1279	1243	1264	1277	1293
		σ	28	34	42	48	11	22	31	36
6, 12, 13	Refuse	Avg.	1095	1158	1177	1227	1156	1179	1197	1256
		σ	31	3	6	17	6	9	6	12
	Grate ash	Avg.	1116	1127	1134	1139	1186	1201	1210	1216
		σ	6	10	13	13	14	16	15	15
	Coll. ash	Avg.	1117	1131	1138	1153	1182	1192	1201	1218
		σ	18	14	15	23	6	6	9	16
50% RDF	Coal	Avg.	1132	1138	1143	1150	1254	1270	1288	1302
		σ	34	30	29	25	6	21	44	61
2, 10, 15	Refuse	Avg.	1099	1141	1164	1217	1136	1158	1177	1240
		σ	19	11	6	6	6	9	11	21
	Grate ash	Avg.	1077	1091	1101	1127	1132	1158	1173	1217
		σ	10	11	14	11	15	20	22	40
	Coll. ash	Avg.	1086	1110	1130	1164	1151	1169	1186	1217
		σ	3	6	11	6	20	14	13	28

(continued)

TABLE D-2. (continued)

Test	Sample		Reducing atmosphere				Oxidizing atmosphere			
			IT	ST	HT	FT	IT	ST	HT	FT
100% Load										
0% RDF	Coal	Avg.	1151	1156	1162	1166	1238	1242	1248	1252
		σ	25	25	26	27	50	51	52	53
11, 31, 32	Refuse	Avg.	-	-	-	-	-	-	-	-
		σ	-	-	-	-	-	-	-	-
	Grate ash	Avg.	1134	1142	1149	1156	1214	1227	1236	1245
		σ	39	40	36	37	23	15	14	17
	Coll. ash	Avg.	1106	1117	1126	1134	1206	1217	1227	1240
		σ	32	32	34	36	14	14	17	21
20% RDF	Coal	Avg.	1178	1190	1195	1201	1249	1252	1256	1262
		σ	22	37	42	46	24	23	23	22
7, 14, 19	Refuse	Avg.	1118	1151	1169	1203	1166	1178	1188	1217
		σ	20	9	18	44	6	13	14	34
	Grate ash	Avg.	1093	1108	1119	1134	1189	1212	1228	1247
		σ	11	9	9	14	6	9	6	6
	Coll. ash	Avg.	1110	1125	1132	1151	1184	1193	1202	1217
		σ	22	12	11	22	12	6	3	14
50% RDF	Coal	Avg.	1130	1157	1166	1174	1235	1239	1243	1264
		σ	28	4	0	4	11	14	16	41
3, 18	Refuse	Avg.	1066	1149	1169	1219	1135	1163	1185	1234
		σ	0	8	12	28	4	4	11	42
	Grate ash	Avg.	1080	1096	1107	1143	1157	1180	1193	1216
		σ	4	12	19	16	19	12	16	32
	Coll. ash	Avg.	1081	1096	1119	1135	1158	1168	1174	1182
		σ	25	11	12	27	12	20	20	23
UNIT 6 - 80% Load										
0% RDF	Coal	Avg.	1143	1148	1152	1155	1237	1242	1246	1251
		σ	17	17	17	15	29	29	28	28
24, 29, 30	Refuse	Avg.	-	-	-	-	-	-	-	-
		σ	-	-	-	-	-	-	-	-
	Grate ash	Avg.	1082	1091	1101	1110	1240	1246	1249	1257
		σ	6	9	11	15	11	12	14	13
	Coll. ash	Avg.	1115	1121	1126	1132	1212	1221	1228	1240
		σ	20	20	20	20	28	28	28	26
20% RDF	Coal	Avg.	1173	1179	1183	1187	1229	1232	1236	1240
		σ	18	18	18	20	12	11	11	11
25, 26, 27	Refuse	Avg.	1114	1123	1134	1154	1154	1164	1173	1193
		σ	9	6	3	6	6	6	3	11
	Grate ash	Avg.	1084	1097	1110	1143	1188	1199	1212	1219
		σ	23	21	24	37	9	6	7	9
	Coll. ash	Avg.	1112	1121	1132	1143	1206	1216	1125	1240
		σ	12	15	14	14	21	20	18	21
50% RDF	Coal	Avg.	1148	1152	1155	1160	1219	1223	1227	1230
		σ	14	13	12	11	13	12	10	9
22, 23, 28	Refuse	Avg.	1093	1132	1143	1162	1140	1159	1173	1195
		σ	56	26	24	33	21	10	8	14
	Grate ash	Avg.	1060	1110	1134	1164	1138	1152	1173	1194
		σ	53	15	17	14	43	37	28	25
	Coll. ash	Avg.	1103	1110	1119	1129	1182	1190	1199	1208
		σ	23	20	17	14	31	28	25	23

a/ Standard deviation.
IT = Initial deformation temperature.
ST = Softening temperature.
HT = Hemispherical temperature.
FT = Fluid temperature.

TABLE D-3. CHEMICAL ANALYSIS (MAJOR ELEMENTS) OF COAL, RDF, AND FUEL MIXTURES ASH

EPA test	% Load/ % RDF	Basis - % mineral ash								
		Al_2O_3	SiO_2	TiO_2	K_2O	CaO	Fe_2O_3	Na_2O	MgO	P_2O_5
UNIT 5 - COAL										
4A	60/0	19.66	34.22	0.65	0.95	18.46	25.19	0.094	0.43	0.32
4B	60/0	19.79	32.74	0.67	0.96	18.57	26.42	0.094	0.43	0.32
20	60/0	21.44	41.04	0.63	1.21	14.44	20.06	0.189	0.696	0.321
21	60/0	20.38	41.41	0.67	1.22	15.22	19.35	0.377	0.895	0.458
36	60/0	18.76	39.46	0.55	1.12	18.91	19.36	0.148	0.514	1.21
Avg.		20.01	37.77	0.63	1.09	17.12	22.08	0.180	0.593	0.526
σ		0.99	4.02	0.05	0.13	2.12	3.44	0.117	0.201	0.387
8	60/20	16.09	39.01	0.60	1.17	18.65	23.65	0.081	0.415	0.298
9A	60/20	20.33	38.81	0.60	1.01	16.35	22.06	0.081	0.431	0.344
9B	60/20	19.37	37.94	0.55	1.02	18.04	21.51	0.863	0.431	0.275
33	60/20	19.18	39.06	0.59	1.08	18.06	20.86	0.135	0.464	0.550
Avg.		18.74	38.71	0.59	1.07	17.78	22.02	0.290	0.435	0.367
σ		1.84	0.52	0.02	0.07	0.99	1.19	0.383	0.021	0.125
1	60/50	21.88	36.36	0.67	1.00	15.68	23.26	0.175	0.464	0.504
34	60/50	17.49	39.72	0.60	1.00	18.38	21.79	0.135	0.464	0.412
35	60/50	21.14	40.37	0.67	1.12	16.37	19.37	0.135	0.431	0.390
Avg.		20.17	38.82	0.65	1.04	16.81	21.47	0.148	0.453	0.435
σ		2.35	2.15	0.04	0.07	1.40	1.96	0.023	0.019	0.060
5	80/0	20.73	36.92	0.64	0.94	17.32	22.44	0.148	0.481	0.344
16	80/0	21.40	40.95	0.67	1.13	12.82	22.11	0.148	0.514	0.229
17	80/0	23.17	40.79	0.61	1.09	12.80	20.60	0.135	0.514	0.275
Avg.		21.77	39.55	0.64	1.05	14.31	21.72	0.144	0.502	0.283
σ		1.26	2.22	0.03	0.10	2.60	0.98	0.008	0.018	0.058
6	80/20	15.06	32.67	0.47	0.93	24.75	24.50	0.822	0.431	0.367
12	80/20	20.64	35.21	0.54	1.10	19.70	21.85	0.054	0.398	0.504
13	80/20	19.36	35.92	0.57	1.10	18.94	23.15	0.054	0.431	0.504
Avg.		18.35	34.60	0.53	1.04	21.13	23.17	0.310	0.420	0.458
σ		2.92	1.71	0.05	0.10	3.16	1.33	0.443	0.019	0.079
2	80/50	20.01	35.42	0.69	0.90	13.09	29.05	0.067	0.431	0.321
10	80/50	22.16	35.59	0.59	1.04	17.06	22.56	0.189	0.497	0.298
15	80/50	21.56	41.22	0.66	1.14	13.42	21.02	0.135	0.547	0.275
Avg.		21.24	37.41	0.65	1.03	14.52	24.21	0.130	0.492	0.298
σ		1.11	3.30	0.05	0.12	2.20	4.26	0.061	0.058	0.023
11	100/0	19.91	33.85	0.59	1.13	21.36	22.23	0.148	0.497	0.298
31	100/0	21.90	42.46	0.68	1.16	11.90	20.70	0.202	0.597	0.390
32	100/0	20.26	41.56	0.58	1.14	16.12	19.67	0.135	0.497	0.023
Avg.		20.69	39.29	0.62	1.14	16.46	20.87	0.162	0.530	0.237
σ		1.06	4.73	0.06	0.02	4.74	1.29	0.036	0.058	0.191
7	100/20	13.10	41.51	0.58	1.11	22.09	20.82	0.094	0.415	0.252
14	100/20	17.90	37.04	0.56	0.94	18.18	24.37	0.135	0.481	0.390
19	100/20	15.82	39.09	0.63	1.22	18.80	23.42	0.135	0.514	0.390
Avg.		15.61	39.21	0.59	1.09	19.69	22.87	0.121	0.470	0.344
σ		2.41	2.24	0.04	0.14	2.10	1.84	0.024	0.050	0.080
3	100/50	21.56	36.58	0.37	1.07	17.10	22.45	0.108	0.464	0.275
18	100/50	19.91	36.94	0.57	1.13	18.47	21.93	0.135	0.531	0.344
Avg.		20.74	36.76	0.47	1.10	17.79	22.19	0.122	0.498	0.310
σ		1.17	0.25	0.14	0.04	0.97	0.37	0.019	0.047	0.049

(continued)

TABLE D-3. (continued)

EPA test	% Load/ % RDF	Basis - % mineral ash								
		Al_2O_3	SiO_2	TiO_2	K_2O	CaO	Fe_2O_3	Na_2O	MgO	P_2O_5
UNIT 6 - COAL										
24	80/0	18.55	38.57	0.96	1.10	16.85	21.04	0.809	1.56	0.573
29	80/0	19.64	37.77	0.90	1.04	17.70	19.42	0.728	2.12	0.733
30	80/0	19.64	36.24	0.82	0.94	17.42	21.98	0.512	1.69	0.733
Avg.		19.28	37.53	0.89	1.03	17.32	20.81	0.683	1.79	0.680
σ		0.63	1.18	0.07	0.08	0.43	1.29	0.154	0.29	0.092
25	80/20	21.04	36.88	0.88	1.01	19.19	17.80	0.661	2.17	0.367
26	80/20	22.92	35.78	0.87	0.93	15.67	20.50	0.944	1.68	0.687
27	80/20	16.15	38.60	0.91	1.10	19.30	21.53	0.647	1.23	0.504
Avg.		20.04	37.09	0.89	1.01	18.05	19.94	0.751	1.69	0.519
σ		3.49	1.42	0.02	0.09	2.06	1.93	0.168	0.47	0.161
22	80/50	16.79	40.57	0.87	1.10	18.40	19.58	0.782	1.34	0.573
23	80/50	17.88	38.40	0.77	1.04	18.12	21.36	0.687	1.29	0.458
28	80/50	17.05	38.60	1.23	1.13	17.73	20.31	0.755	2.45	0.710
Avg.		17.24	39.19	0.96	1.09	18.08	20.42	0.741	1.69	0.580
σ		0.57	1.20	0.24	0.05	0.34	0.89	0.049	0.66	0.126
UNIT 5 - RDF										
4A	60/0	0	0	0	0	0	0	0	0	0
4B	60/0	0	0	0	0	0	0	0	0	0
20	60/0	0	0	0	0	0	0	0	0	0
21	60/0	0	0	0	0	0	0	0	0	0
36	60/0	0	0	0	0	0	0	0	0	0
Avg.		0	0	0	0	0	0	0	0	0
σ		0	0	0	0	0	0	0	0	0
8	60/20	15.27	42.43	1.909	2.789	24.59	5.432	4.597	2.139	0.8478
9A	60/20	17.98	42.72	2.379	2.569	19.98	5.138	5.581	2.752	0.8936
9B	60/20	18.15	43.13	2.401	1.729	20.17	5.187	5.581	2.752	0.8936
33	60/20	17.00	44.49	2.928	2.550	18.23	5.101	6.026	2.852	0.8249
Avg.		17.10	43.19	2.404	2.409	20.74	5.215	5.446	2.624	0.8650
σ		1.32	0.91	0.416	0.466	2.71	0.149	0.604	0.327	0.0343
1	60/50	16.58	44.33	2.392	2.870	20.73	4.305	5.608	2.703	0.4812
34	60/50	18.17	44.89	2.446	2.533	17.21	5.590	5.729	2.819	0.6187
35	60/50	18.16	44.88	2.445	2.532	17.20	5.589	5.729	2.835	0.6187
Avg.		17.64	44.70	2.428	2.645	18.38	5.161	5.689	2.786	0.5729
σ		0.92	0.32	0.031	0.195	2.04	0.742	0.070	0.072	0.0794
5	80/0	0	0	0	0	0	0	0	0	0
16	80/0	0	0	0	0	0	0	0	0	0
17	80/0	0	0	0	0	0	0	0	0	0
Avg.		0	0	0	0	0	0	0	0	0
σ		0	0	0	0	0	0	0	0	0
6	80/20	11.84	44.24	1.880	2.068	26.51	6.078	4.624	2.238	0.5270
12	80/20	15.94	45.09	1.967	2.529	20.86	4.847	5.365	2.752	0.6416
13	80/20	16.12	48.63	1.988	2.485	18.10	4.899	4.839	2.222	0.7103
Avg.		14.63	45.99	1.945	2.361	21.82	5.275	4.943	2.404	0.6263
σ		2.42	2.33	0.057	0.254	4.29	0.696	0.381	0.301	0.0926
2	80/50	16.18	43.26	2.957	2.334	18.83	7.158	6.079	2.487	0.7013
10	80/50	16.23	45.86	2.021	2.572	21.86	5.327	4.826	0.7793	0.5270
15	80/50	17.68	44.62	2.156	2.371	20.41	4.598	5.203	2.421	0.5499
Avg.		16.70	44.58	2.378	2.426	20.37	5.694	5.369	1.896	0.5927
σ		0.85	1.30	0.506	0.128	1.52	1.319	0.643	0.967	0.0947

(continued)

TABLE D-3. (continued)

EPA test	% Load/ % RDF	Basis - % mineral ash								
		Al_2O_3	SiO_2	TiO_2	K_2O	CaO	Fe_2O_3	Na_2O	MgO	P_2O_5
11	100/0	0	0	0	0	0	0	0	0	0
31	100/0	0	0	0	0	0	0	0	0	0
32	100/0	0	0	0	0	0	0	0	0	0
Avg.		0	0	0	0	0	0	0	0	0
σ		0	0	0	0	0	0	0	0	0
7	100/20	15.76	42.85	2.584	2.501	23.43	4.418	5.203	2.736	0.5270
14	100/20	16.90	46.97	2.275	2.356	18.77	4.388	5.176	2.570	0.5958
19	100/20	13.18	41.31	1.848	2.491	27.57	5.304	4.327	3.333	0.6416
Avg.		15.28	43.71	2.236	2.449	23.26	4.703	4.902	2.880	0.5881
σ		1.91	2.93	0.370	0.081	4.40	0.520	0.498	0.401	0.0577
3	100/50	16.43	43.36	2.606	2.389	22.01	4.561	5.850	2.106	0.6874
18	100/50	14.51	42.23	1.747	2.127	27.42	4.329	4.448	2.686	0.5041
Avg.		15.47	42.80	2.177	2.258	24.72	4.445	5.149	2.396	0.5958
σ		1.36	0.80	0.607	0.185	3.83	0.164	0.991	0.410	0.1296
UNIT 6 - RDF										
24	80/0	0	0	0	0	0	0	0	0	0
29	80/0	0	0	0	0	0	0	0	0	0
30	80/0	0	0	0	0	0	0	0	0	0
Avg.		0	0	0	0	0	0	0	0	0
σ		0	0	0	0	0	0	0	0	0
25	80/20	18.46	43.67	2.308	2.485	22.01	4.349	3.505	2.504	0.7103
26	80/20	14.99	43.18	1.874	2.451	21.77	6.921	5.675	2.421	0.7103
27	80/20	16.02	45.97	2.279	2.149	18.23	6.056	5.122	3.134	1.031
Avg.		16.49	44.27	2.154	2.362	20.67	5.775	4.767	2.686	0.8172
σ		1.78	1.49	0.243	0.185	2.12	1.309	1.128	0.390	0.1852
22	80/50	15.76	44.61	2.335	2.335	20.68	5.503	5.769	2.487	0.5270
23	80/50	16.37	46.31	2.380	2.524	18.39	4.616	6.106	2.454	0.8478
28	80/50	16.94	49.85	2.241	2.779	14.79	4.841	5.244	2.487	0.8249
Avg.		16.36	46.92	2.319	2.546	17.95	4.987	5.706	2.476	0.7332
σ		0.59	2.67	0.071	0.223	2.97	0.461	0.434	0.019	0.1790
UNIT 5 - FUEL (COAL + RDF)										
4A	60/0	19.66	34.22	0.65	0.95	18.46	25.19	0.094	0.43	0.32
4B	60/0	19.79	32.74	0.67	0.96	18.57	26.42	0.094	0.43	0.32
20	60/0	21.44	41.04	0.63	1.21	14.44	20.06	0.189	0.696	0.321
21	60/0	20.38	41.41	0.67	1.22	15.22	19.35	0.377	0.895	0.458
36	60/0	18.76	39.46	0.55	1.12	18.91	19.36	0.148	0.514	1.21
Avg.		20.01	37.77	0.63	1.09	17.12	22.08	0.180	0.593	0.526
σ		0.99	4.02	0.05	0.13	2.12	3.44	0.117	0.201	0.387
8	60/20	15.82	40.12	1.03	1.71	20.61	17.63	1.57	0.9850	0.4798
9A	60/20	19.52	40.15	1.21	1.54	17.59	16.26	1.97	1.23	0.5323
9B	60/20	18.95	39.72	1.18	1.26	18.77	15.92	2.48	1.23	0.4869
33	60/20	18.74	40.15	1.06	1.34	18.09	17.71	1.31	0.9416	0.6050
Avg.		18.26	40.04	1.12	1.46	18.77	16.88	1.83	1.10	0.5260
σ		1.66	0.21	0.09	0.20	1.32	0.92	0.51	0.15	0.0576

(continued)

TABLE D-3. (continued)

EPA test	% Load/ % RDF	Basis - % mineral ash								
		Al_2O_3	SiO_2	TiO_2	K_2O	CaO	Fe_2O_3	Na_2O	MgO	P_2O_5
1	60/50	18.38	41.62	1.81	2.23	19.01	10.74	3.76	1.94	0.4889
34	60/50	17.94	43.12	1.81	2.01	17.61	11.14	3.81	2.01	0.5479
35	60/50	18.82	43.88	2.05	2.22	17.02	8.65	4.49	2.30	0.5679
Avg.		18.38	42.87	1.89	2.15	17.88	17.88	4.02	2.08	0.5349
σ		0.44	1.15	0.14	0.12	1.02	1.34	0.41	0.19	0.0411
5	80/0	20.73	36.92	0.64	0.94	17.32	22.44	0.148	0.481	0.344
16	80/0	21.40	40.95	0.67	1.13	12.82	22.11	0.148	0.514	0.229
17	80/0	23.17	40.79	0.61	1.09	12.80	20.60	0.135	0.514	0.275
Avg.		21.77	39.55	0.64	1.05	14.31	21.72	0.144	0.502	0.283
σ		1.26	2.22	0.03	0.10	2.60	0.98	0.08	0.018	0.058
6	80/20	14.00	36.49	0.9353	1.306	25.33	18.42	2.08	1.03	0.4198
12	80/20	18.64	39.35	1.15	1.71	20.19	14.63	2.31	1.40	0.5624
13	80/20	18.08	40.94	1.13	1.65	18.61	15.94	1.94	1.14	0.5854
Avg.		16.91	38.93	1.07	1.56	21.38	16.33	2.11	1.19	0.5225
σ		2.53	2.26	0.12	0.22	3.51	1.92	0.19	0.19	0.0897
2	80/50	17.76	40.02	2.02	1.74	16.46	16.21	3.59	1.64	0.5440
10	80/50	18.56	41.83	1.46	1.97	19.98	12.09	3.01	0.6685	0.4371
15	80/50	19.51	43.01	1.45	1.79	17.11	12.36	2.81	1.53	0.4199
Avg.		18.61	41.62	1.64	1.83	17.85	13.55	3.14	1.28	0.4670
σ		0.88	1.51	0.33	0.12	1.87	2.30	0.41	0.53	0.0672
11	100/0	19.91	33.85	0.59	1.13	21.36	22.23	0.148	0.497	0.298
31	100/0	21.90	42.46	0.68	1.16	11.90	20.70	0.202	0.597	0.390
32	100/0	20.26	41.56	0.58	1.14	16.12	19.67	0.135	0.497	0.023
Avg.		20.69	39.29	0.62	1.14	16.46	20.87	0.162	0.530	0.237
σ		1.06	4.73	0.06	0.02	4.74	1.29	0.036	0.058	0.191
7	100/20	13.90	41.91	1.19	1.53	22.49	15.87	1.64	1.12	0.3350
14	100/20	17.56	41.10	1.24	1.51	18.47	16.50	2.14	1.31	0.4729
19	100/20	14.65	40.07	1.17	1.78	22.68	15.41	1.99	1.76	0.5012
Avg.		15.37	41.03	1.20	1.20	21.21	15.93	1.92	1.40	0.4364
σ		1.93	0.92	0.04	0.15	2.38	0.55	0.26	0.33	0.0889
3	100/50	18.67	40.40	1.63	1.81	19.87	12.36	3.35	1.39	0.5076
18	100/50	16.63	40.15	1.28	1.73	23.90	11.25	2.75	1.84	0.4411
Avg.		17.65	40.28	1.46	1.77	21.89	11.81	3.05	1.62	0.4744
σ		1.44	0.18	0.25	0.06	2.85	0.78	0.42	0.32	0.0470
UNIT 6 - FUEL (COAL + RDF)										
24	80/0	18.55	38.57	0.96	1.10	16.85	21.04	0.809	1.56	0.573
29	80/0	19.64	37.77	0.90	1.04	17.70	19.42	0.728	2.12	0.733
30	80/0	19.64	36.24	0.82	0.94	17.42	21.98	0.512	1.69	0.733
Avg.		19.28	37.53	0.89	1.03	17.32	20.81	0.683	1.79	0.680
σ		0.63	1.18	0.07	0.08	0.43	1.29	0.154	0.29	0.092
25	80/20	20.29	38.85	1.29	1.44	20.01	13.90	1.49	2.27	0.4665
26	80/20	20.41	38.12	1.19	1.41	17.60	16.20	2.44	1.91	0.6944
27	80/20	16.11	40.97	1.35	1.44	18.96	16.55	2.09	1.84	0.6736
Avg.		18.94	39.31	1.28	1.43	18.86	15.55	2.01	2.01	0.6115
σ		2.45	1.48	0.08	0.02	1.21	1.44	0.48	0.23	0.1260
22	80/50	16.13	43.15	1.81	1.89	19.86	10.58	3.97	2.07	0.5436
23	80/50	16.84	43.83	1.88	2.06	18.31	9.86	4.41	2.09	0.7258
28	80/50	16.98	45.53	1.85	2.15	15.92	10.56	3.52	2.47	0.7808
Avg.		18.94	44.17	1.85	2.03	18.03	10.33	3.97	2.21	0.6834
σ		0.46	1.23	0.04	0.13	1.98	0.41	0.45	0.23	0.1242

TABLE D-4a. CHEMICAL ANALYSIS (MAJOR ELEMENTS) OF GRATE ASH

EPA test	% Load/ % RDF	Basis - % mineral ash								
		Al_2O_3	SiO_2	TiO_2	K_2O	CaO	Fe_2O_3	Na_2O	MgO	P_2O_5
UNIT 5										
4A	60/0	13.18	32.63	0.6098	1.612	34.76	16.20	0.1348	0.5306	0.3437
4B	60/0	10.98	28.80	0.5801	1.462	41.26	15.92	0.1348	0.5306	0.3437
20	60/0	13.57	29.86	0.8905	1.449	25.49	26.61	0.7010	1.011	0.4125
21	60/0	13.66	30.06	0.8963	1.458	25.66	26.78	0.5662	0.8954	0.02291
36	60/0	12.40	29.57	0.7006	1.433	30.22	24.14	0.4718	0.8125	0.2521
Avg.		12.76	30.18	0.7355	1.483	31.48	21.93	0.4017	0.7560	0.2750
σ		1.11	1.45	0.1509	0.073	6.67	5.46	0.2569	0.2175	0.1520
8	60/20	9.973	33.48	0.5475	1.349	32.85	19.01	1.604	0.8456	0.3437
9A	60/20	7.990	34.99	0.5510	1.304	33.17	17.85	2.440	1.244	0.4583
9B	60/20	11.14	35.74	0.6287	1.375	35.48	12.65	1.550	1.028	0.4125
33	60/20	11.67	32.53	0.5227	1.473	26.16	27.64	ND	ND	ND
Avg.		10.19	34.19	0.5625	1.375	31.92	19.29	1.865	1.0392	0.4048
σ		1.63	1.45	0.0459	0.071	4.01	6.22	0.499	0.1994	0.0577
1	60/50	11.62	43.88	0.9398	1.487	24.16	12.71	3.141	1.393	0.6645
34	60/50	12.40	43.46	1.047	1.625	24.71	16.76	ND	ND	ND
35	60/50	12.31	45.35	1.514	1.771	25.86	13.20	ND	ND	ND
Avg.		12.11	44.23	0.9416	1.628	24.91	14.22	3.141	1.393	0.6645
σ		0.43	0.99	0.3387	0.142	0.87	2.21	0	0	0
5	80/0	14.24	30.03	0.4817	1.466	38.41	14.37	0.1348	0.5306	0.3437
16	80/0	14.50	30.72	0.8292	0.1238	24.26	28.32	0.3370	0.6632	0.2521
17	80/0	12.30	28.11	0.8381	1.364	25.92	30.41	0.2157	0.5969	0.2521
Avg.		13.68	29.62	0.7163	0.9846	29.53	24.37	0.2292	0.5969	0.2826
σ		1.20	1.35	0.2032	0.7472	7.73	8.72	0.1018	0.0663	0.0529
6	80/20	9.598	30.16	0.6166	1.092	23.68	31.75	1.739	1.028	0.3437
12	80/20	12.84	19.92	0.5818	1.144	24.98	36.32	2.858	1.343	0.0229
13	80/20	9.716	31.17	0.6340	1.148	21.11	32.09	2.372	1.161	0.5958
Avg.		10.718	27.08	0.6108	1.128	23.26	33.39	2.323	1.177	0.3208
σ		1.839	6.22	0.0266	0.0312	1.97	2.55	0.561	0.158	0.2871
2	80/50	11.94	35.82	0.8200	1.145	16.50	28.58	3.662	1.426	0.5041
10	80/50	8.671	37.54	0.8523	1.311	21.80	24.37	3.437	1.492	0.5270
15	80/50	10.49	42.24	0.9252	1.264	15.76	24.04	3.303	1.459	0.5270
Avg.		10.37	38.53	0.8658	1.240	18.02	25.66	3.334	1.459	0.5194
σ		1.64	3.32	0.0539	0.086	3.29	2.53	0.092	0.033	0.0132
11	100/0	8.191	25.20	0.4329	1.056	24.97	38.63	0.5122	0.6632	0.3437
31	100/0	14.23	35.72	0.6840	1.436	18.40	29.59	ND	ND	ND
32	100/0	10.30	28.87	0.5000	1.364	29.07	29.90	ND	ND	ND
Avg.		10.91	29.33	0.5390	1.285	24.15	32.71	0.5122	0.6632	0.3437
σ		3.06	5.34	0.1300	0.202	5.38	5.13	0	0	0
7	100/20	11.20	35.65	0.6108	1.407	30.06	17.47	2.116	1.128	0.3666
14	100/20	12.32	31.74	0.6846	1.125	19.17	31.47	1.914	1.094	0.4812
19	100/20	11.60	32.83	0.9345	1.520	26.17	23.53	2.184	1.161	0.06874
Avg.		11.71	33.41	0.7433	1.351	25.13	24.16	2.071	1.128	0.5194
σ		0.57	2.02	0.1696	0.203	5.52	7.02	0.140	0.034	0.2129
3	100/50	9.624	34.15	0.6789	1.052	19.01	31.06	2.885	1.128	0.4125
18	100/50	10.04	38.02	0.9373	1.525	24.87	18.80	3.478	1.724	0.5958
Avg.		9.83	36.09	0.8081	1.289	21.94	24.93	3.182	1.426	0.5042
σ		0.29	2.74	0.1827	0.334	4.14	8.67	0.419	0.421	0.1296

(continued)

TABLE D-4a. (continued)

EPA test	% Load/ % RDF	Basis - % mineral ash								
		Al_2O_3	SiO_2	TiO_2	K_2O	CaO	Fe_2O_3	Na_2O	MgO	P_2O_5
UNIT 6										
24	80/0	13.76	34.01	0.8128	1.468	24.80	23.07	0.08090	1.476	0.5270
29	80/0	15.05	38.94	0.8465	1.301	18.22	23.31	0.4179	1.343	0.5729
30	80/0	14.09	38.40	0.8466	1.339	17.87	25.12	0.5662	1.227	0.5499
Avg.		14.30	37.12	0.8353	1.369	20.30	23.83	0.3550	1.349	0.5499
σ		0.67	2.70	0.0195	0.088	3.90	1.12	0.2487	0.125	0.0230
25	80/20	14.73	42.65	1.073	1.393	17.89	17.36	1.685	2.421	0.8020
26	80/20	13.58	37.31	0.7894	1.284	22.76	20.22	2.130	1.642	0.2750
27	80/20	11.64	43.47	0.8781	1.311	18.90	18.47	2.817	1.990	0.5270
Avg.		13.32	41.14	0.9135	1.329	19.85	19.85	2.211	2.018	0.5499
σ		1.56	3.34	0.1451	0.057	2.57	1.44	0.570	0.390	0.2636
22	80/50	11.45	48.73	1.018	1.320	18.15	10.74	5.823	2.056	0.7103
23	80/50	11.82	47.19	0.7901	1.285	18.82	11.46	5.864	2.039	0.7333
28	80/50	11.64	47.43	0.8786	1.442	19.46	11.17	4.705	2.603	0.6645
Avg.		11.64	47.78	0.8956	1.349	18.81	11.12	5.464	2.233	0.7027
σ		0.19	0.83	0.1149	0.082	0.66	0.36	0.658	0.321	0.0350

ND = None detected.

TABLE D-4b. CHEMICAL ANALYSIS (MAJOR ELEMENTS) OF COLLECTOR ASH

EPA test	% Load/ % RDF	Basis - % mineral ash								
		Al_2O_3	SiO_2	TiO_2	K_2O	CaO	Fe_2O_3	Na_2O	MgO	P_2O_5
UNIT 5										
4A	60/0	14.82	33.54	0.8319	1.604	19.58	28.45	0.2292	0.5969	0.3437
4B	60/0	14.82	33.54	0.8319	1.604	19.58	28.45	0.2292	0.5969	0.3437
20	60/0	17.44	36.75	1.064	1.858	21.35	18.32	1.281	1.409	0.5270
21	60/0	17.67	37.23	1.077	1.882	21.62	18.56	0.5931	0.9783	0.3895
36	60/0	14.65	35.84	0.6249	1.712	20.47	24.84	0.2966	0.7130	0.8478
Avg.		15.88	35.38	0.8859	1.732	20.52	23.72	0.5258	0.8588	0.4903
σ		1.53	1.75	0.1885	0.134	0.96	5.04	0.4481	0.3448	0.2135
8	60/20	16.62	42.24	1.128	2.205	23.22	11.86	0.9166	1.277	0.5499
9A	60/20	16.59	42.63	1.270	2.102	22.84	10.99	1.429	1.459	0.6874
9B	60/20	16.59	42.63	1.270	2.102	22.84	10.99	1.429	1.459	0.6874
33	60/20	15.70	39.87	1.045	1.901	20.09	18.00	1.591	1.310	0.4812
Avg.		16.38	41.84	1.178	2.078	22.25	12.96	1.341	1.376	0.6015
σ		0.45	1.33	0.111	0.127	1.45	3.38	0.293	0.096	0.1031
1	60/50	NS	NS	NS	NS	NS	NS	NS	NS	NS
34	60/50	16.45	45.09	1.464	2.183	18.19	9.929	3.801	2.222	0.6645
35	60/50	15.60	44.83	1.676	2.209	19.73	8.658	3.990	2.321	0.9853
Avg.		16.03	44.96	1.570	2.196	18.96	9.294	3.896	2.272	0.8249
σ		0.60	0.18	0.150	0.018	1.09	0.899	0.134	0.070	0.2268
5	80/0	13.94	34.96	0.8958	1.752	21.39	25.81	0.05392	0.8125	0.3895
16	80/0	14.73	36.95	0.9188	1.852	19.10	24.89	0.5122	0.7296	0.3208
17	80/0	16.20	36.70	0.8575	1.728	18.01	25.27	0.3235	0.6301	0.2750
Avg.		14.96	36.20	0.8907	1.777	19.50	25.32	0.2965	0.7241	0.3284
σ		1.15	1.08	0.0310	0.066	1.73	0.46	0.2303	0.0913	0.0576
6	80/20	13.80	34.71	1.152	1.800	18.62	26.44	1.267	1.592	0.6187
12	80/20	13.32	38.39	1.105	2.130	24.44	16.03	2.130	1.741	0.7103
13	80/20	13.45	38.74	1.115	2.149	24.66	16.18	1.146	1.724	0.8478
Avg.		13.52	37.28	1.124	2.026	22.57	19.55	1.514	1.686	0.7256
σ		0.25	2.23	0.025	0.196	3.43	5.97	0.537	0.082	0.1153
2	80/50	14.56	44.36	1.732	2.325	18.24	13.34	2.494	2.056	0.8936
10	80/50	14.74	43.44	1.501	2.310	20.59	13.89	1.429	1.459	0.6416
15	80/50	14.66	42.96	1.582	2.023	17.46	16.74	2.305	1.608	0.6645
Avg.		14.65	43.59	1.605	2.219	18.76	14.66	2.076	1.708	0.7332
σ		0.09	0.71	0.117	0.170	1.63	1.83	0.568	0.311	0.1394
11	100/0	16.99	41.23	0.7890	2.037	24.92	12.59	0.3909	2.558	0.6964
31	100/0	16.65	38.78	0.8305	1.686	17.79	22.14	0.6875	0.8622	0.5729
32	100/0	15.79	37.38	0.7464	1.866	20.05	22.63	0.3100	0.7461	0.4812
Avg.		16.48	39.13	0.7886	2.219	20.92	19.12	0.4628	1.389	0.5835
σ		0.62	1.95	0.0421	0.176	3.64	5.66	0.1988	1.014	0.1080
7	100/20	15.98	43.06	1.285	2.316	22.96	11.12	1.227	1.459	0.5958
14	100/20	15.08	37.83	1.471	2.081	18.18	21.26	1.995	1.492	0.6187
19	100/20	11.51	32.57	0.9132	1.508	25.96	23.34	1.928	1.608	0.6645
Avg.		14.19	37.82	1.223	1.968	22.37	18.57	1.717	1.520	0.6263
σ		2.36	5.25	0.284	0.416	3.92	6.54	0.425	0.078	0.0350
3	100/50	15.59	37.33	1.538	2.109	19.54	19.73	1.914	1.542	0.7103
18	100/50	10.11	38.26	0.9290	1.534	25.03	18.92	2.480	1.990	0.7562
Avg.		12.85	37.80	1.234	1.822	22.29	19.33	2.197	1.766	0.7333
σ		3.87	0.66	0.431	0.407	3.88	0.57	0.400	0.317	0.0325

(continued)

TABLE D-4b. (continued)

EPA test	% Load/ % RDF	Basis - % mineral ash								
		Al_2O_3	SiO_2	TiO_2	K_2O	CaO	Fe_2O_3	Na_2O	MgO	P_2O_5
UNIT 6										
24	80/0	14.64	35.16	1.549	2.097	24.31	17.95	1.564	2.023	0.7103
29	80/0	15.30	35.82	0.8907	1.525	20.40	22.39	0.6201	2.321	0.7332
30	80/0	14.52	37.01	0.9059	1.633	20.18	22.18	0.6201	2.106	0.8478
Avg.		14.82	36.00	1.115	1.752	21.63	20.84	0.9647	2.150	0.7638
σ		0.42	0.94	0.376	0.304	2.32	2.51	0.5969	0.154	0.0737
25	80/20	15.29	37.18	1.539	2.083	23.03	15.93	2.157	1.990	0.8020
26	80/20	15.94	33.85	1.492	2.004	23.41	18.53	2.116	1.923	0.7332
27	80/20	15.92	39.89	1.264	1.992	19.31	16.36	2.251	2.222	0.8020
Avg.		15.72	36.97	1.432	2.026	21.92	16.94	2.175	2.045	0.7791
σ		0.37	3.03	0.147	0.049	2.27	1.39	0.069	0.157	0.0397
22	80/50	12.96	35.11	1.331	1.950	23.72	20.57	1.523	2.106	0.7332
23	80/50	15.71	39.17	1.714	2.194	23.81	11.88	2.710	2.023	0.7791
28	80/50	18.01	42.75	1.746	2.223	18.21	10.61	3.141	2.587	0.7332
Avg.		15.56	39.01	1.597	2.122	21.91	14.35	2.458	2.239	0.7485
σ		2.53	3.82	0.231	0.150	3.21	5.42	0.838	0.305	0.0265

NS =

TABLE D-5. BASE/ACID RATIO SLAGGING AND FOULING INDICES

		Coal			RDF			Fuel			Grate ash			Collector ash		
EPA	Nominal load/ nominal RDF	Basic acid ratio	Fouling index	Slagging index	Basic acid ratio	Fouling index	Slagging index	Basic acid ratio	Fouling index	Slagging index	Basic acid ratio	Fouling index	Slagging index	Basic acid ratio	Fouling index	Slagging index
UNIT 5																
4A	60/0	0.83	0.08	7.10	-	-	-	0.83	0.08	7.10	1.15	0.16	4.80	1.03	0.24	1.68
4B	60/0	0.87	0.08	7.50	-	-	-	0.87	0.08	7.50	1.47	0.20	4.60	1.03	0.24	1.68
20	60/0	0.58	0.11	5.70	-	-	-	0.58	0.11	5.70	1.25	0.87	3.95	0.80	1.03	1.73
21	60/0	0.58	0.22	3.50	-	-	-	0.58	0.22	3.50	1.24	0.70	3.93	0.78	0.46	1.44
36	60/0	0.68	0.10	4.80	-	-	-	0.68	0.10	4.80	1.34	0.63	4.62	0.94	0.28	1.71
Avg.		0.71	0.12	5.72	-	-	-	0.71	0.12	5.72	1.23	0.51	4.49	0.91	0.45	1.65
σ[a]		0.14	0.06	1.65	-	-	-	0.14	0.06	1.65	0.08	0.32	0.37	0.12	0.34	0.12
8	60/20	0.79	0.06	6.30	0.66	3.05	0.53	0.75	1.17	4.30	1.27	2.03	4.44	0.66	0.60	1.53
9A	60/20	0.67	0.05	5.10	0.57	3.19	0.19	0.63	1.25	3.39	1.29	3.14	4.07	0.64	0.92	1.44
9B	60/20	0.73	0.62	5.60	0.56	3.10	0.19	0.66	1.64	3.55	1.10	1.70	3.46	0.64	0.92	1.44
33	60/20	0.69	0.09	5.20	0.54	3.25	0.16	0.66	0.86	4.05	ND	ND	ND	0.76	1.21	1.40
Avg.		0.72	0.21	5.60	0.58	3.15	0.27	0.68	1.23	3.82	1.22	2.29	3.99	0.68	0.91	1.45
σ		0.05	0.28	0.50	0.05	0.09	0.18	0.05	0.32	0.42	0.11	0.75	0.49	0.06	0.25	0.06
1	60/50	0.69	0.12	5.20	0.57	3.21	0.13	0.61	2.29	1.76	0.76	2.39	2.47	NS	NS	NS
34	60/50	0.72	0.10	4.90	0.52	2.97	0.14	0.58	2.22	1.53		ND		0.58	2.19	0.66
35	60/50	0.60	0.08	3.80	0.52	2.97	0.17	0.54	2.41	0.99		ND		0.59	2.37	0.54
Avg.		0.67	0.10	4.60	0.53	3.04	0.15	0.58	2.31	1.43		2.39		0.59	2.28	0.60
σ		0.06	0.02	0.70	0.03	0.14	0.02	0.04	0.10	0.39		0		0.01	0.13	0.08
5	80/0	0.71	0.10	5.00	-	-	-	0.71	0.11	5.00	1.23	0.17	4.69	1.00	0.05	2.07
16	80/0	0.58	0.09	4.00	-	-	-	0.58	0.09	4.00	1.17	0.40	4.45	0.90	0.46	1.73
17	80/0	0.54	0.07	3.90	-	-	-	0.54	0.07	3.90	1.72	0.37	4.79	0.86	0.28	1.65
Avg.		0.61	0.09	4.30	-	-	-	0.61	0.09	4.30	1.37	0.31	4.64	0.92	0.26	1.82
σ		0.09	0.02	0.60	-	-	-	0.09	0.02	0.60	0.30	0.13	0.17	0.08	0.20	0.22
6	80/20	1.07	0.89	8.20	0.72	3.31	0.44	0.94	1.95	5.16	1.47	2.55	5.48	1.00	1.27	2.55
12	80/20	0.76	0.04	5.80	0.58	3.10	0.23	0.68	1.57	3.21	2.00	5.71	5.50	0.88	1.87	3.71
13	80/20	0.78	0.04	6.10	0.49	2.36	0.22	0.65	1.28	3.27	1.40	3.31	5.76	0.86	0.98	3.63
Avg.		0.87	0.32	6.70	0.59	2.92	0.30	0.76	1.60	3.88	1.62	3.86	5.58	0.91	1.38	3.30
σ		0.17	0.49	1.30	0.11	0.50	0.13	0.16	0.34	1.11	0.33	1.65	0.16	0.08	0.45	0.65
2	80/50	0.78	0.05	7.50	0.59	3.59	0.35	0.66	2.38	2.94	1.05	3.42	2.23	0.63	1.58	1.25
10	80/50	0.70	0.13	5.20	0.55	2.66	0.32	0.61	1.84	2.07	1.11	3.83	3.21	0.66	0.95	1.50
15	80/50	0.57	0.08	3.70	0.54	2.83	0.25	0.56	1.56	1.91	0.85	2.82	1.46	0.68	1.56	1.77
Avg.		0.67	0.09	5.50	0.56	3.03	0.32	0.61	1.93	2.31	1.00	3.36	2.30	0.66	1.37	1.54
σ		0.10	0.04	1.90	0.02	0.50	0.05	0.05	0.42	0.60	0.13	0.51	0.88	0.02	0.36	0.27

(continued)

TABLE D-5. (continued)

EPA	Nominal load/ nominal RDF	Coal			RDF			Fuel			Grate ash			Collector ash		
		Basic acid ratio	Fouling index	Slagging index	Basic acid ratio	Fouling index	Slagging index	Basic acid ratio	Fouling index	Slagging index	Basic acid ratio	Fouling index	Slagging index	Basic acid ratio	Fouling index	Slagging index
11	100/0	0.84	0.12	5.80	-	-	-	0.84	0.12	5.80	1.95	1.00	5.45	0.72	0.28	1.54
31	100/0	0.53	0.11	3.80	-	-	-	0.53	0.11	3.80	NS	NS	NS	0.77	0.53	1.59
32	100/0	0.60	0.08	4.50	-	-	-	0.60	0.08	4.50	NS	NS	NS	0.84	0.26	1.61
Avg.		0.66	0.10	4.70	-	-	-	0.66	0.10	4.70	1.95	1.00	5.45	0.78	0.36	1.58
σ		0.16	0.02	1.00	-	-	-	0.16	0.02	1.00	0	0	0	0.06	0.15	0.03
7	100/20	0.80	0.08	6.20	0.63	3.30	0.65	0.75	1.23	4.33	1.10	2.33	4.50	0.65	0.79	1.51
14	100/20	0.80	0.11	5.70	0.50	2.60	0.20	0.67	1.43	3.16	1.22	2.34	3.83	0.83	1.65	2.19
19	100/20	0.80	0.11	5.80	0.76	3.30	0.38	0.78	1.60	3.43	1.20	2.63	4.92	0.21	2.33	3.44
Avg.		0.80	0.10	5.90	0.63	3.10	0.41	0.73	1.40	3.64	1.18	2.43	4.41	0.89	1.59	2.38
σ		0.01	0.02	0.30	0.13	0.39	0.23	0.06	0.16	0.61	0.07	0.17	0.55	0.29	0.77	0.98
3	100/50	0.70	0.08	5.70	0.59	3.46	0.37	0.64	2.14	2.69	1.24	3.58	4.02	0.82	1.58	1.84
18	100/50	0.74	0.10	5.00	0.70	3.12	0.81	0.71	1.96	2.54	1.03	3.58	3.08	1.01	2.51	2.85
Avg.		0.72	0.09	5.30	0.65	3.29	0.59	0.68	2.05	2.62	1.14	3.58	3.55	0.92	2.05	2.35
σ		0.02	0.02	0.5	0.08	0.24	0.32	0.10	0.12	0.11	0.15	0.00	0.67	0.13	0.66	0.71
UNIT 6																
24	80/0	0.71	0.58	2.80	-	-	-	0.71	0.58	2.80	1.05	0.08	2.28	0.93	1.46	1.54
29	80/0	0.70	0.51	2.40	-	-	-	0.70	0.51	2.40	0.81	0.34	1.64	0.91	0.56	1.44
30	80/0	0.75	0.38	4.30	-	-	-	0.75	0.38	4.30	0.86	0.49	1.43	0.89	0.55	1.60
Avg.		0.72	0.49	3.20	-	-	-	0.72	0.49	3.20	0.91	0.30	1.78	0.91	0.86	1.53
σ		0.03	0.10	1.00	-	-	-	0.03	0.10	1.00	0.12	0.20	0.45	0.02	0.52	0.09
25	80/20	0.69	0.46	2.50	0.54	1.90	0.25	0.65	1.00	1.77	0.70	1.18	1.01	0.84	1.81	1.67
26	80/20	0.67	0.63	2.80	0.65	3.71	0.33	0.66	1.61	2.05	0.93	2.00	1.35	0.93	2.00	2.08
27	80/20	0.79	0.51	3.40	0.54	2.77	0.17	0.70	1.46	2.20	0.78	2.19	1.28	0.74	1.66	1.20
Avg.		0.72	0.53	2.70	0.58	2.79	0.25	0.67	1.35	2.01	0.80	1.78	1.21	0.84	1.82	1.65
σ		0.06	0.09	0.20	0.06	0.91	0.08	0.03	0.34	0.22	0.12	0.54	0.18	0.10	0.16	0.44
22	80/50	0.71	0.55	2.80	0.59	3.38	0.19	0.63	2.49	1.12	0.62	3.62	0.70	1.01	1.54	2.33
23	80/50	0.75	0.51	3.40	0.52	3.20	0.23	0.59	2.59	1.09	0.66	3.87	0.86	0.75	2.04	1.23
28	80/50	0.75	0.56	2.30	0.44	2.29	0.16	0.54	1.89	0.78	0.66	3.09	0.56	0.59	1.85	0.82
Avg.		0.73	0.54	2.80	0.52	2.96	0.25	0.58	1.35	1.00	0.65	3.53	0.70	0.78	1.81	1.47
σ		0.02	0.03	0.50	0.07	0.59	0.03	0.05	0.38	0.19	0.02	0.40	0.15	0.21	0.25	0.80

a/ Standard deviation.

TABLE D-6. BASE/ACID RATIO, SLAGGING/FOULING FACTOR CALCULATION PARAMETERS

		Actual		Multiplication factor for oxide calculation				Coal	RDF	Fuel		
EPA test	Nominal % Load/ % RDF	Steam load (%)	RDF heat (%)	Coal	RDF	Grate ash	Collector ash	Moisture free sulfur kg/kg	Moisture free sulfur kg/kg	Weighted average sulfur kg/kg	Fraction coal kg coal/kg fuel	Fraction RDF kg RDF/kg fuel
UNIT 5												
4A	60/0	60.00	0	1.591	0	1.869	1.041	0.0860	0	0.0860	1.0	0
4B	60/0	60.00	0	1.601	0	2.075	1.041	0.0860	0	0.0860	1.0	0
20	60/0	59.47	0	1.278	0	1.114	1.139	0.0980	0	0.0980	1.0	0
21	60/0	59.47	0	1.290	0	1.122	1.154	0.0607	0	0.0607	1.0	0
36	60/0	58.95	0	1.489	0	1.420	0.9646	0.0697	0	0.0697	1.0	0
Avg.		59.59	0					0.0801	0	0.0801	1.0	0
σ		0.44	0					0.0148	0	0.0148	0	0
8	60/20	60.00	22.3	1.219	1.182	1.656	1.468	0.0799	0.0080	0.0576	0.6694	0.3306
9A	60/20	60.00	24.7	1.329	1.285	1.629	1.436	0.0770	0.0034	0.0535	0.6574	0.3426
9B	60/20	60.00	24.8	1.336	1.297	1.768	1.436	0.0771	0.0034	0.0535	0.6574	0.3426
33	60/20	60.00	16.4	1.400	1.067	1.433	1.116	0.0758	0.0029	0.0617	0.8000	0.2000
Avg.		60.00	21.5					0.0775	0.0044	0.0566	0.6961	0.3040
σ		0.0	3.84					0.0017	0.0024	0.0039	0.0695	0.0695
1	60/50	61.05	54.7	1.723	1.467	1.450	NS	0.0752	0.0023	0.0288	0.3397	0.6603
34	60/50	59.47	55.6	1.482	1.214	1.402	1.185	0.0671	0.0028	0.0263	0.3427	0.6573
35	60/50	60.53	68.3	1.364	1.511	1.389	1.222	0.0634	0.0032	0.0185	0.2222	0.7778
Avg.		60.35	58.83					0.0686	0.0028	0.0245	0.3015	0.6985
σ		0.81	7.70					0.0060	0.0005	0.0054	0.0687	0.0687
5	80/0	80.00	0	1.420	0	1.824	1.081	0.0699	0	0.0699	1.0	0
16	80/0	80.53	0	1.417	0	1.084	1.204	0.0688	0	0.0688	1.0	0
17	80/0	81.05	0	1.335	0	1.102	1.101	0.0718	0	0.0718	1.0	0
Avg.		80.5	0					0.0702	0	0.702	1.0	0
σ		0.53	0					0.0015	0	0.0015	0	0
6	80/20	78.95	22.7	1.276	1.310	1.428	1.371	0.0772	0.0062	0.0550	0.6700	0.3300
12	80/20	78.95	32.3	1.349	1.047	1.630	1.444	0.0769	0.0040	0.0472	0.5754	0.4246
13	80/20	81.05	28.4	1.403	1.079	1.413	1.457	0.0775	0.0045	0.0501	0.6052	0.3948
Avg.		79.7	27.2					0.0772	0.0049	0.0508	0.6169	0.3831
σ		1.21	4.72					0.0003	0.0012	0.0039	0.0484	0.0484
2	80/50	80.00	47.3	1.482	1.066	1.543	1.335	0.0964	0.0037	0.0444	0.4137	0.5863
10	80/50	79.47	49.9	1.343	1.016	1.444	1.375	0.0737	0.0059	0.0339	0.3924	0.6076
15	80/50	77.89	40.2	1.356	1.495	1.419	1.261	0.0649	0.0047	0.0343	0.4728	0.5272
Avg.		79.1	45.1					0.0783	0.0048	0.0375	0.4263	0.5737
σ		1.10	5.01					0.0163	0.0011	0.0060	0.0417	0.0417

(continued)

TABLE D-6. (continued)

EPA test	Nominal % Load/ % RDF	Actual		Multiplication factor for oxide calculation				Coal	RDF	Fuel	Fraction coal kg coal/kg fuel	Fraction RDF kg RDF/kg fuel
		Steam load (%)	RDF heat (%)	Coal	RDF	Grate ash	Collector ash	Moisture free sulfur kg/kg	Moisture free sulfur kg/kg	Weighted average sulfur kg/kg		
11	100/0	97.37	0	1.453	0	1.533	1.567	0.0697	0	0.0697	1.0	0
31	100/0	97.89	0	1.327	0	1.206	1.036	0.0716	0	0.0716	1.0	0
32	100/0	93.16	0	1.479	0	1.274	1.056	0.0746	0	0.0746	1.0	0
Avg.		96.1	0					0.0720	0	0.0720	1.0	0
σ		2.59	0					0.0025	0	0.0025	0	0
7	100/20	97.89	21.3	1.407	1.284	1.558	1.450	0.0746	0.0104	0.0578	0.6981	0.3019
14	100/20	94.74	27.2	1.377	1.373	1.422	1.432	0.0720	0.0039	0.0474	0.6057	0.3973
19	100/20	92.63	30.2	1.492	1.945	1.206	1.203	0.0727	0.0050	0.0439	0.5580	0.4420
Avg.		95.1	25.6					0.0737	0.0064	0.0497	0.6206	0.3804
σ		2.65	4.43					0.0024	0.0035	0.0072	0.0712	0.0716
3	100/50	92.63	41.6	1.487	1.238	1.483	1.415	0.0810	0.0062	0.0421	0.4361	0.5639
18	100/50	96.84	45.0	1.443	1.451	1.157	1.223	0.0675	0.0116	0.0355	0.3935	0.6065
Avg.		94.7	42.6					0.0743	0.0089	0.0388	0.4148	0.5852
σ		2.98	2.40					0.0095	0.0038	0.0047	0.0301	0.0301
UNIT 6												
24	80/0	80.40	0	1.131	0	1.088	1.169	0.0392	0	0.0392	1.0	0
29	80/0	79.20	0	1.079	0	1 195	1.111	0.0346	0	0.0346	1.0	0
30	80/0	81.20	0	1.169	0	1.216	1.158	0.0567	0	0.0567	1.0	0
Avg.		80.27	0					0.0435	0	0.0435	1.0	0
σ		1.01	0					0.0117	0	0.0117	0	0
25	80/20	80.80	20.0	1.156	1.207	1.230	1.168	0.0363	0.0046	0.0273	0.7102	0.2898
26	80/20	81.20	21.8	0.967	1.168	1.117	1.326	0.0423	0.0051	0.0309	0.6833	0.3167
27	80/20	79.20	22.0	1.313	1.009	1.233	1.120	0.0438	0.0031	0.0314	0.6782	0.3218
Avg.		80.40	20.73					0.0408	0.0043	0.0299	0.6906	0.3094
σ		1.06	1.08					0.0040	0.0010	0.0022	0.0172	0.0172
22	80/50	79.20	48.9	1.076	1.201	1.163	1.097	0.0397	0.0033	0.0178	0.3610	0.6390
23	80/50	79.20	55.4	1.200	1.226	1.130	1.162	0.0456	0.0044	0.0185	0.3130	0.6870
28	80/50	78.40	49.5	1.122	1.174	1.265	1.197	0.0311	0.0038	0.0145	0.3838	0.6162
Avg.		78.93	44.87					0.0388	0.0038	0.0169	0.3526	0.6474
σ		0.46	11.48					0.0073	0.0006	0.0021	0.0361	0.0361

APPENDIX E - MISCELLANEOUS PERFORMANCE DATA

TABLE E-1. FORCED AND INDUCED DRAFT FAN MOTOR AMPERES

EPA test	% Load/ % RDF	Forced draft fan amps	Induced draft fan amps
UNIT 6			
24	80/0	49	240
29	80/0	48	230
30	80/0	40	173
25	80/20	49	270
26	80/20	49	273
27	80/20	48	268
22	80/50	45	276
23	80/50	45	267
28	80/50	47	280

TABLE E-2. FLUE GAS AND COMBUSTION AIR VOLUME FLOW RATES

EPA test	% Load/ % RDF	Steam load	RDF heat	Flue gas collector inlet (m^3/S)	Air in Std. m^3/S
UNIT 5					
4A	60/0	60.00	0	27.71	18.72
4B	60/0	60.00	0	25.18	17.20
20	60/0	59.47	0	23.18	13.95
21	60/0	59.47	0	22.35	12.24
36	60/0	58.95	0	25.44	15.48
Avg.		59.58	0	24.77	15.52
σ		0.44	0	2.10	2.56
8	60/20	60.00	21.7	31.36	20.17
9A	60/20	60.00	24.1	37.14	16.92
9B	60/20	60.00	24.2	32.94	18.20
33	60/20	60.00	16.0	28.86	15.61
Avg.		60.00	21.5	32.58	17.73
σ		0	3.84	3.48	1.94
1	60/50	61.05	53.9	29.18	17.33
34	60/50	59.47	54.9	30.81	15.98
35	60/50	60.53	67.7	30.22	13.48
Avg.		60.35	58.83	30.07	17.73
σ		0.81	7.70	0.83	1.95
5	80/0	80.00	0	31.31	20.83
16	80/0	80.53	0	33.95	21.35
17	80/0	81.05	0	32.39	20.72
Avg.		80.53	0	32.55	20.82
σ		0.53	0	1.33	0.49
6	80/20	78.95	22.2	32.48	19.97
12	80/20	78.95	31.6	33.40	17.10
13	80/20	81.05	27.7	34.32	16.18
Avg.		79.65	27.2	33.40	17.75
σ		1.21	4.72	0.92	1.98
2	80/50	80.00	46.5	31.57	15.51
10	80/50	79.47	49.2	34.19	17.60
15	80/50	77.89	39.5	33.84	19.73
Avg.		79.12	45.1	33.20	17.61
σ		1.10	5.01	1.42	2.11

(continued)

TABLE E-2. (continued)

EPA test	% Load/ % RDF	Steam load	RDF heat	Flue gas collector inlet (m^3/S)	Air in Std. m^3/S
11	100/0	97.37	0	30.03	15.58
31	100/0	97.89	0	31.52	18.25
32	100/0	93.16	0	32.94	19.27
Avg.		96.14	0	31.50	17.61
σ		2.59	0	1.46	1.91
7	100/20	97.89	20.8	33.87	20.20
14	100/20	94.74	26.6	33.82	18.10
19	100/20	92.63	29.5	32.73	17.27
Avg.		96.14	25.6	33.47	18.52
σ		2.64	4.43	0.64	1.51
3	100/50	92.63	40.9	33.49	24.10
18	100/50	96.84	44.3	33.53	18.73
Avg.		94.74	42.6	33.51	21.42
σ		2.98	2.40	0.03	3.80
24	80/0	80.40	0	38.75	22.03
29	80/0	79.20	0	37.83	22.95
30	80/0	81.20	0	29.74	16.27
Avg.		80.27	0	35.44	20.42
σ		1.01	0	4.96	3.62
25	80/20	80.80	19.5	42.88	23.08
26	80/20	81.20	21.2	43.95	24.65
27	80/20	79.20	21.5	41.44	22.20
Avg.		80.27	20.7	42.76	23.31
σ		1.06	1.08	1.26	1.24
22	80/50	79.20	47.8	42.43	19.13
23	80/50	79.20	54.6	41.68	19.13
28	80/50	78.40	32.2	41.97	25.77
Avg.		78.93	44.9	42.02	21.34
σ		0.46	11.5	0.31	3.83

TABLE E-3. SIZE DISTRIBUTION OF RDF DISCHARGED FROM ATLAS BIN
(as received, all percents by weight)

Date (1976)	Sample No.a/	Size (mm) standard ASTM E-11 designation						Geometric	
		% larger than	% smaller than					Mean	Standard
		63	63	38.1	19.0	9.5	4.8	diameter	deviation
6-8	EPA 1	2.62	97.38	92.21	77.10	45.94	25.78	10.2	2.38
6-10	EPA 2	4.50	95.50	86.62	71.78	44.28	23.31	11.3	2.55
6-15	EPA 3	0.75	99.25	93.55	77.86	48.76	23.87	9.9	2.28
6-23	EPA 6	5.38	94.62	88.75	69.40	39.03	20.25	12.0	2.46
6-25	EPA 7	9.15	90.85	77.13	52.53	29.19	13.83	16.4	2.58
6-28	EPA 8	9.12	90.88	81.38	64.98	38.05	19.57	13.3	2.66
6-30	EPA 9A	4.91	95.09	88.44	69.70	40.48	20.77	11.8	2.47
6-30	EPA 9B	1.44	98.56	87.96	63.58	31.07	14.55	13.7	2.31
7-2	EPA 10	1.07	98.93	92.02	72.13	32.37	15.00	12.4	2.19
7-8	EPA 12	4.97	95.03	88.53	69.96	32.00	18.13	12.8	2.38
7-8	EPA 13	8.47	91.53	85.96	66.18	28.48	12.94	14.3	2.37
7-16	EPA 14	3.71	96.29	88.50	71.49	30.64	18.06	12.7	2.34
7-17	EPA 15	7.26	92.74	84.99	69.59	34.64	19.58	12.8	2.52
7-23	EPA 18	4.47	95.53	88.83	69.50	30.56	14.31	13.2	2.29
7-24	EPA 19	3.48	96.52	86.86	68.87	37.06	19.31	12.4	2.45
8-5	EPA 22	2.31	97.69	88.25	68.28	40.72	19.77	11.9	2.43
8-6	EPA 23	5.85	94.15	89.23	74.42	41.62	23.43	11.1	2.48
8-10	EPA 25	1.45	98.55	84.10	61.26	32.27	15.31	14.0	2.41
8-11	EPA 26	3.41	96.59	91.66	79.50	52.63	25.82	9.6	2.38
8-12	EPA 27	7.77	92.23	79.23	57.88	31.98	17.21	14.9	2.63
8-13	EPA 28	4.02	95.98	84.26	64.96	35.92	18.41	13.1	2.51
8-25	EPA 33	14.15	85.85	71.15	51.06	29.59	14.33	17.4	2.74
8-26	EPA 34	6.33	93.67	90.26	65.34	34.98	18.56	12.8	2.43
8-26	EPA 35	50.49	49.51	40.45	28.88	24.89	13.48	28.8	3.15
Mean		6.96	93.04	84.60	66.09	36.13	18.57	13.1	2.54

a/ Sample number corresponds to environmental sampling test designation.

TABLE E-4. FUEL-RDF UTILIZATION

EPA test	% Load/ % RDF	Total ash combustible loss based on:[a]		Ash combustible loss due to RDF based on:[b]	
		Calculated ash flow (%)	Measured ash flow (%)	Calculated ash flow (%)	Measured ash flow (%)
UNIT 5					
4A	60/0	5.5	2.9	-	-
4B	60/0	4.3	2.5	-	-
20	60/0	5.4	4.4	-	-
21	60/0	5.4	4.7	-	-
36	60/0	8.3	5.7	-	-
Avg.		5.8	4.0	-	-
σ		1.4	1.3	-	-
8	60/20	5.6	4.8	4.8	7.2
9A	60/20	3.9	4.2	2.0	4.7
9B	60/20	3.5	3.5	3.7	1.8
33	60/20	4.4	4.6	2.7	7.7
Avg.		4.4	4.3	0.9	5.4
σ		0.9	0.6	3.9	2.7
1	60/50	5.2	4.3	4.6	4.5
34	60/50	3.6	4.0	1.8	4.0
35	60/50	3.7	4.0	2.7	4.0
Avg.		4.1	4.1	3.0	4.2
σ		0.9	0.2	1.4	0.3
5	80/0	5.2	4.6	-	-
16	80/0	5.2	4.1	-	-
17	80/0	5.5	4.6	-	-
Avg.		5.3	4.4	-	-
σ		0.2	0.3	-	-
6	80/20	6.0	5.0	8.7	6.8
12	80/20	5.4	5.0	5.6	6.3
13	80/20	5.6	5.1	6.4	6.7
Avg.		5.7	5.0	6.9	6.6
σ		0.3	0.1	1.6	0.3
2	80/50	4.1	3.9	2.7	3.2
10	80/50	4.4	3.8	3.5	4.0
15	80/50	5.5	4.2	5.7	3.7
Avg.		4.7	3.9	4.0	3.7
σ		0.7	0.2	1.5	0.4

(continued)

TABLE E-4. (continued)

EPA test	% Load/ % RDF	Total ash combustible loss based on:a/ Calculated ash flow (%)	Total ash combustible loss based on:a/ Measured ash flow (%)	Ash combustible loss due to RDF based on:b/ Calculated ash flow (%)	Ash combustible loss due to RDF based on:b/ Measured ash flow (%)
11	100/0	4.7	4.3	-	-
31	100/0	6.0	6.0	-	-
32	100/0	5.3	5.3	-	-
Avg.		5.3	5.2	-	-
σ		0.6	0.8	-	-
7	100/20	6.2	4.7	9.3	2.7
14	100/20	4.4	3.8	1.9	0.0
19	100/20	6.7	4.8	9.9	4.1
Avg.		5.7	4.4	7.0	2.3
σ		1.2	0.6	4.4	2.1
3	100/50	5.7	3.9	6.4	2.1
18	100/50	8.5	5.4	12.4	5.7
Avg.		7.1	4.7	9.4	3.9
σ		2.0	1.1	4.3	2.6
UNIT 6					
24	80/0	2.4	2.7	-	-
29	80/0	2.5	2.4	-	-
30	80/0	2.2	1.8	-	-
Avg.		2.4	2.3	-	-
σ		0.2	0.5	-	-
25	80/20	2.0	2.3	0.6	2.3
26	80/20	2.0	2.1	0.6	1.2
27	80/20	2.7	1.9	3.6	0.6
Avg.		2.2	2.1	1.6	1.4
σ		0.4	0.2	1.7	0.9
22	80/50	3.3	2.8	4.3	3.3
23	80/50	2.6	2.0	2.8	1.7
28	80/50	2.0	2.1	1.7	1.8
Avg.		2.7	2.3	2.9	2.2
σ		0.7	0.4	1.3	0.9

a/ Based on total fuel heat input.

b/ Based on RDF heat input.

Table E-5. Stack Heat Losses--Indirect Boiler Efficiency

EPA test	% Load/ % RDF	Heat loss free moisture (%)	Heat loss day flue gas (%)
UNIT 5			
4A	60/0	1.9	14.3
4B	60/0	1.9	13.2
20	60/0	1.7	11.6
21	60/0	2.0	10.1
36	60/0	1.5	11.4
Avg.		1.8	12.1
σ		0.2	1.7
8	60/20	2.6	14.9
9A	60/20	2.7	14.7
9B	60/20	2.7	15.7
33	60/20	1.8	12.8
Avg.		2.4	14.5
σ		0.4	1.2
1	60/50	2.8	15.0
34	60/50	2.7	9.5
35	60/50	4.1	12.3
Avg.		3.2	12.3
σ		0.8	2.8
5	80/0	2.0	13.6
16	80/0	1.8	13.5
17	80/0	1.8	13.9
Avg.		1.8	13.6
σ		0.1	0.2
6	80/20	2.4	13.4
12	80/20	2.6	12.2
13	80/20	2.4	12.0
Avg.		2.5	12.5
σ		0.1	0.8
2	80/50	3.5	11.7
10	80/50	2.8	12.1
15	80/50	3.0	13.8
Avg.		3.1	12.5
σ		0.4	1.1

Table E-5 (continued)

EPA test	% Load/ % RDF	Heat loss free moisture (%)	Heat loss day flue gas (%)
11	100/0	1.7	9.2
31	100/0	1.8	9.4
32	100/0	1.7	10.6
Avg.		1.7	9.7
σ		0.1	0.7
7	100/20	2.4	12.8
14	100/20	2.4	10.8
19	100/20	2.7	9.9
Avg.		2.5	11.2
σ		0.1	1.5
3	100/50	4.5	14.7
18	100/50	3.2	10.4
Avg.		3.8	12.5
σ		0.9	3.0
UNIT 6			
24	80/0	2.3	11.3
29	80/0	2.3	11.6
30	80/0	2.4	8.1
Avg.		2.3	10.3
σ		0.1	2.0
25	80/20	2.8	11.8
26	80/20	2.9	12.1
27	80/20	2.8	11.3
Avg.		2.8	11.7
σ		0.1	0.4
22	80/50	4.8	9.7
23	80/50	4.0	11.1
28	80/50	4.3	11.7
Avg.		4.4	10.9
σ		0.4	1.0

Table E-6. Measured Ash Flow-Rate Ratios

EPA test	% Load/ % RDF	Total ash (kg/hr)	Ash ratio kg ash/100 kg steam			
			Collector	Grate	Stack particulate	Total
UNIT 5						
4A	60/0	585.14	0.49	1.49	0.28	2.26
4B	60/0	607.82	0.49	1.49	0.38	2.36
20	60/0	802.87	0.70	2.29	0.14	3.13
21	60/0	784.73	0.49	2.29	0.28	3.06
36	60/0	875.45	0.91	1.86	0.65	3.42
Avg.		731.20	0.62	1.88	0.35	2.85
σ		127.83	0.19	0.40	0.19	0.51
8	60/20	1,038.74	1.25	2.56	0.21	4.02
9A	60/20	1,088.64	1.20	2.46	0.55	4.21
9B	60/20	1,002.46	1.20	2.46	0.22	3.88
33	60/20	1,029.67	1.13	2.32	0.53	3.98
Avg.		1,039.88	1.20	2.45	0.38	4.02
σ		35.98	0.05	0.10	0.19	0.14
1	60/50	1,034.21	0.77	2.95	0.21	3.93
34	60/50	1,111.32	0.82	3.01	0.51	4.34
35	60/50	1,120.39	0.75	2.99	0.56	4.33
Avg.		1,088.64	0.78	2.98	0.43	4.29
σ		47.36	0.04	0.03	0.19	0.23
5	80/0	1,070.50	1.11	1.85	0.15	3.11
16	80/0	1,102.25	1.24	1.80	0.14	3.18
17	80/0	1,097.71	1.01	1.79	0.34	3.14
Avg.		1,090.15	1.12	1.82	0.21	3.14
σ		17.17	0.12	0.03	0.11	0.04
6	80/20	1,247.40	1.12	2.46	0.09	3.67
12	80/20	1,238.33	1.27	2.26	0.11	3.64
13	80/20	1,188.43	1.07	2.20	0.13	3.40
Avg.		1,224.72	1.16	2.29	0.11	3.57
σ		31.75	0.10	0.10	0.02	0.15
2	80/50	1,170.29	0.86	2.45	0.09	3.40
10	80/50	1,238.33	0.91	2.58	0.13	3.62
15	80/50	1,192.97	0.99	2.43	0.13	3.55
Avg.		1,200.53	0.92	2.49	0.12	3.52
σ		34.64	0.06	0.08	0.02	0.11

Table E-6 (continued)

EPA test	% Load/ % RDF	Total ash (kg/hr)	Ash ratio kg ash/100 kg steam			
			Collector	Grate	Stack particulate	Total
11	100/0	1,324.51	1.09	1.96	0.11	3.16
31	100/0	1,681.95	NT	NT	-	3.99
32	100/0	1,722.32	NT	NT	-	4.29
Avg.		1,576.26	1.09	1.96	0.11	3.81
σ		218.95	-	-	-	0.59
7	100/20	1,265.54	0.46	2.41	0.13	3.00
14	100/20	1,265.54	0.53	2.47	0.10	3.10
19	100/20	1,528.63	0.59	3.12	0.12	3.83
Avg.		1,353.24	0.53	2.67	0.12	3.31
σ		151.90	0.07	0.39	0.02	0.45
3	100/50	1,406.16	0.68	2.75	0.09	3.52
18	100/50	1,356.26	0.69	2.41	0.15	3.25
Avg.		1,381.21	0.68	2.58	0.12	3.39
σ		35.28	0.00	0.24	0.04	0.19
UNIT 6						
24	80/0	1,020.60	0.63	1.41	0.20	2.24
29	80/0	762.05	0.69	0.84	0.17	1.70
30	80/0	762.05	0.53	1.02	0.11	1.66
Avg.		848.23	0.62	1.09	0.16	1.86
σ		149.27	0.08	0.29	0.05	0.33
25	80/20	1,211.11	0.95	1.52	0.17	2.64
26	80/20	1,143.07	0.72	1.54	0.22	2.48
27	80/20	898.13	0.39	1.31	0.30	2.00
Avg.		1,084.10	0.69	1.45	0.23	2.38
σ		164.61	0.28	0.13	0.07	0.34
22	80/50	1,138.54	0.70	1.51	0.33	2.54
23	80/50	1,106.78	0.44	1.72	0.31	2.47
28	80/50	1,374.41	0.73	2.07	0.29	3.09
Avg.		1,206.58	0.63	1.76	0.31	2.70
σ		146.21	0.16	0.28	0.02	0.34

APPENDIX F - INTERIM SAMPLING OF RDF

LABORATORY RESULTS

Fourteen weeks of random sampling of RDF discharged from the Atlas bin to the boilers is now complete. Tables F-1, F-2, and F-3 show the laboratory analysis results received to date.

Table F-4 shows the sampling schedule and the identification of each sample number as to the date and day of the week it was taken. The following tables (F-1, F-2, and F-5) use only the sample number for identification.

Table F-1 presents the bulk density, moisture, heating value and proximate and ultimate analysis. Table F-2 presents the chemical analysis of RDF ash. Table F-3 shows the ash fusion temperatures of RDF ash. Figure F-1 shows the procedure for determination of bulk density.

RDF ash is relatively high in silica (SiO_2), one of the major constituents determining the slagging characteristics of an ash. It is desirable to have low silica content. However, interpretation of these ash analysis results, as well as the ash fusion temperatures, moisture, bulk density, heating value, and proximate and ultimate analysis can best be made after the same categories of data are available for the coal used at Ames.

Although not part of the random sampling schedule, on 9 different days, samples of RDF discharged from the Atlas bin were sized using laboratory sieve machines to determine the screen size. This was done to check out the screening procedure. Results from these nine tests are presented in Table F-6.

In early March 1976, the second stage shredder was taken out of service due to a bearing failure and was not placed back in service until March 28, 1976. Therefore, samples No. 1 and 2 are single shredded RDF. The major effect of single versus double shredding is on particle size and possibly bulk density.

The single stage data were deleted from the mean calculations for the particle size because its effect was very apparent. However, the single shred data were included in all the other data constituents because there was not a definite change in values due to single stage shredding. The screen size distribution is reported in detail. However, to make comparisons easier, the geometric mean diameter and the geometric standard deviation were calculated.

TABLE F-1. BULK DENSITY, HEATING VALUE, AND PROXIMATE AND ULTIMATE ANALYSIS OF RDF DISCHARGED FROM ATLAS BIN
(as received, all percents by weight, ASTM method D271 for all values except bulk density)

Sample No. (test day)	Bulk density (kg/m^3)	Heating value (kJ/kg)	Moisture (%)	Ash (%)	Volatile matter (%)	Fixed carbon (%)
1	134.7	13,328	22.00	11.12	57.54	9.34
2	97.0	12,406	19.38	17.44	58.21	4.97
3	152.2	11,475	29.24	21.38	48.56	0.82
4	104.4	13,812	18.65	15.24	59.21	6.90
5	129.5	13,120	19.71	17.99	56.69	5.61
6	157.0	12,084	31.77	19.39	46.57	2.27
7	127.8	11,875	28.32	15.61	52.48	3.59
8	122.5	13,948	20.97	13.74	57.22	8.07
9	156.0	15,219	19.92	19.48	55.55	5.05
10	137.6	13,099	25.61	13.55	54.46	6.38
11	122.4	11,909	25.10	22.52	51.12	1.26
12	116.1	13,413	20.82	18.25	56.16	4.77
13	125.5	13,914	20.92	18.77	54.99	5.32
14	113.8	13,104	20.05	18.76	56.32	4.87
Mean	128.3	13,050	23.03	17.37	54.65	4.94

Sample No. (test day)	Carbon (%)	Hydrogen (%)	Oxygen (%)	Sulfur (%)	Chlorine (%)	Nitrogen (%)
1	32.58	4.91	28.32	0.46	0.25	0.36
2	32.27	4.36	25.40	0.60	0.26	0.29
3	28.36	4.21	15.84	0.23	0.20	0.54
4	33.59	4.61	27.14	0.29	0.16	0.32
5	32.41	4.88	24.02	0.33	0.17	0.49
6	27.98	4.64	14.92	0.64	0.25	0.41
7	29.41	4.98	19.94	0.88	0.22	0.64
8	33.90	5.08	25.21	0.60	0.14	0.36
9	32.66	4.96	21.99	0.44	0.21	0.34
10	31.33	4.68	24.00	0.30	0.20	0.33
11	26.57	4.20	20.51	0.27	0.26	0.57
12	30.23	5.08	24.56	0.29	0.32	0.45
13	31.03	4.95	23.38	0.36	0.19	0.40
14	29.72	5.18	25.10	0.26	0.59	0.34
Mean	30.86	4.77	22.88	0.43	0.24	0.42

TABLE F-2. LABORATORY ANALYSIS OF RDF ASH
Ash of RDF discharged from Atlas bin, ASTM method D2795
(% by weight)

Sample No. (test day)	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	P_2O_5
1	42.54	11.90	3.91	1.42	1.12
2	41.82	13.53	2.99	1.76	0.99
3	49.95	10.20	8.13	1.11	0.66
4	46.80	13.30	3.69	1.41	0.52
5	50.20	11.70	3.93	1.68	0.70
6	51.60	11.60	3.76	1.67	0.28
7	44.25	10.40	3.65	1.20	0.78
8	54.10	8.45	4.46	1.07	0.36
9	54.00	11.30	4.45	1.35	0.96
10	43.22	18.17	3.46	1.30	0.88
11	51.41	9.39	2.91	1.28	0.73
12	49.18	11.61	4.28	1.47	1.25
13	48.27	11.73	4.57	1.55	0.99
14	47.32	11.20	5.90	1.96	0.85
Mean	48.19	11.75	4.29	1.45	0.79

Sample No. (test day)	CaO	MgO	Na_2O	K_2O
1	14.75	2.49	4.83	1.70
2	15.48	2.26	3.68	1.52
3	11.60	3.19	3.46	2.16
4	12.90	2.55	3.88	1.64
5	12.90	2.19	3.90	1.57
6	11.80	2.18	4.60	1.73
7	15.30	1.95	3.73	1.54
8	11.90	2.46	5.08	1.65
9	10.45	2.13	4.19	1.87
10	10.40	2.04	4.07	2.26
11	13.72	2.57	5.22	1.67
12	12.14	2.63	4.86	2.10
13	12.52	2.37	4.59	2.04
14	12.02	2.30	5.13	1.75
Mean	12.71	2.38	4.37	1.80

TABLE F-3. FUSION TEMPERATURE OF RDF ASH
Ash of RDF discharge from Atlas bin

ASTM Method D1857

Nomenclature

IT = Initial deformation temperature
ST = Softening temperature (H = W)
HT = Hemispherical temperature ($H = \frac{W}{2}$)
FT = Fluid temperature
H = Cone height
W = Cone width

Date (1976)	Sample No. (test day)	Temperature (°C)							
		Reducing atmosphere				Oxidizing atmosphere			
		IT	ST	HT	FT	IT	ST	HT	FT
March 17	1	1110	1116	1121	1127	1121	1127	1132	1138
March 23	2	1121	1127	1132	1138	1132	1138	1143	1149
April 2	3	1127	1138	1143	1149	1149	1154	1160	1166
April 7	4	1132	1143	1154	1160	1143	1154	1166	1171
April 15	5	1127	1138	1149	1160	1138	1149	1160	1171
April 19	6	1127	1132	1138	1143	1138	1143	1149	1154
April 27	7	1127	1132	1138	1143	1138	1143	1149	1154
May 6	8	1154	1171	1199	1249	1171	1204	1238	1282
May 12	9	1149	1160	1171	1182	1166	1193	1210	1227
May 20	10	1038	1138	1176	1210	1149	1193	1216	1243
May 25	11	1032	1154	1176	1204	1166	1188	1210	1227
June 4	12	1038	1166	1188	1221	1182	1204	1227	1249
June 7	13	1121	1166	1182	1216	1188	1193	1221	1232
June 14	14	1082	1116	1149	1182	1104	1132	1149	1188
	Mean	1106	1143	1158	1177	1149	1165	1181	1197
Standard deviation		41.47	18.15	23.57	37.42	23.48	28.62	37.10	45.53
Confidence interval at 95% confidence ± coefficient		72	31	41	65	41	50	64	79

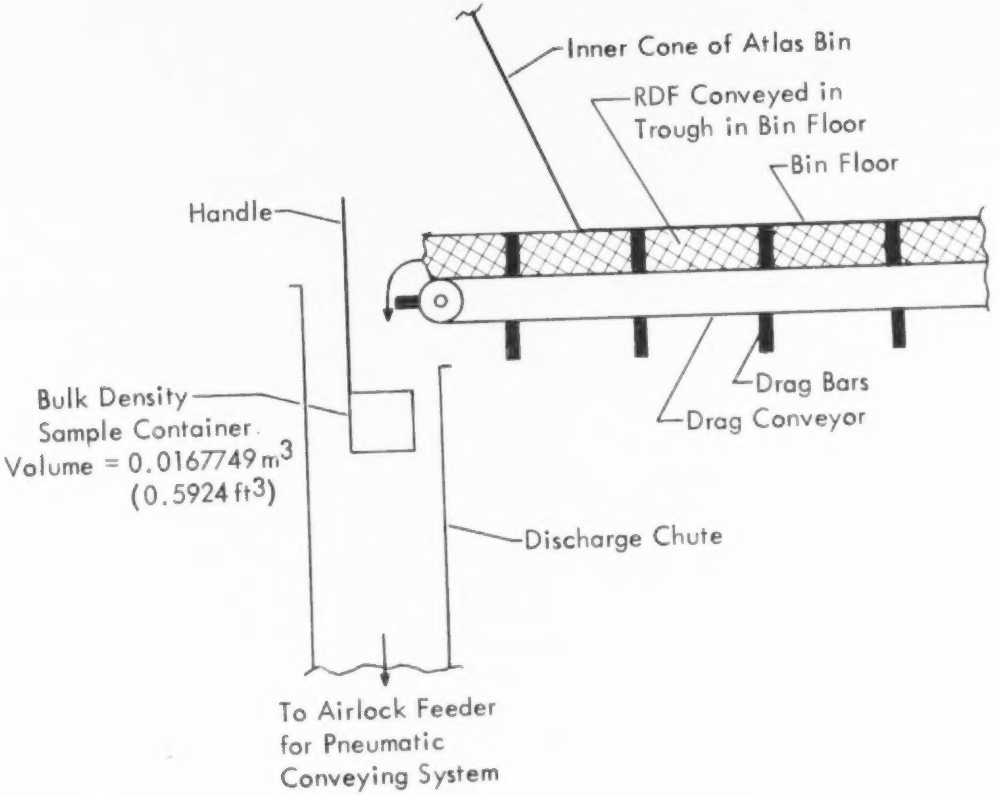
TABLE F-4. SAMPLING SCHEDULE (RANDOM SAMPLING OF RDF AT ATLAS BIN DISCHARGE)

Sample No.	Day of week	Date (1976)
1	Wednesday	March 17[a]
2	Tuesday	March 23[a]
3	Friday	April 2
4	Wednesday	April 7
5	Thursday	April 15
6	Monday	April 19
7	Tuesday	April 27
8	Thursday	May 6
9	Wednesday	May 12
10	Thursday	May 20
11	Tuesday	May 25
12	Friday	June 4
13	Monday	June 7
14	Monday	June 14

a/ Single stage shredding due to second stage shredder out of service because of bearing failure. Second stage shredder back in service on March 28, 1976, and tests 3 through 14 are double shredded refuse.

TABLE F-5. MOISTURE FREE AND ASH FREE VALUES OF DAILY SAMPLES OF RDF DISCHARGED FROM ATLAS BIN
(all percents by weight)

Sample No. (test day)	Moisture % as received	Ash % As received	Ash % Moisture free	Heating value (kJ/kg) As received	Heating value (kJ/kg) Moisture free	Heating value (kJ/kg) Moisture and ash free
1	22.00	11.12	14.26	13,328	17,087	19,929
2	19.38	17.44	21.63	12,406	15,388	19,635
3	29.24	21.38	30.21	11,475	16,217	23,237
4	18.65	15.24	18.73	13,812	16,978	20,891
5	19.71	17.99	22.41	13,120	16,341	21,061
6	31.77	19.39	28.42	12,084	17,711	24,743
7	28.32	15.61	21.78	11,875	16,567	21,180
8	20.97	13.74	17.39	13,948	17,649	21,364
9	19.92	19.48	24.33	15,219	19,005	25,116
10	25.61	13.55	18.21	13,099	17,609	21,530
11	25.10	22.52	30.07	11,909	15,900	22,737
12	20.82	18.25	23.05	13,413	16,940	22,014
13	20.92	18.77	23.74	13,914	17,595	23,072
14	20.05	18.76	23.46	13,104	16,390	21,414
n	14	14	14	14	14	14
$\bar{X}$	23.03	17.37	22.69	13,050	16,956	21,995
Sx	4.212	3.170	4.685	1,021.6	922.8	1,619.4
C.V. %	18.29	18.25	20.64	7.83	5.44	7.36


Inner Cone of Atlas Bin
RDF Conveyed in Trough in Bin Floor
Bin Floor
Handle
Bulk Density Sample Container Volume = 0.0167749 m3 (0.5924 ft3)
Drag Bars
Drag Conveyor
Discharge Chute
To Airlock Feeder for Pneumatic Conveying System

PROCEDURE

Sample container placed below drag conveyor discharge. container filled and then removed from discharge chute. Container then leveled off and weight determined.

Two or more conveyors normally used for conveying refuse. Above procedure repeated for each conveyor in use. Bulk density reported is total weight of RDF collected divided by total volume.

$$\text{Bulk Density} = \frac{\Sigma \text{ sample container weight}}{(\text{Number of samples})\ (0.0167749\ \text{m}^3)}$$

Figure F-1. Procedure for determination of bulk density.

TABLE F-6. SIZE DISTRIBUTION OF RDF DISCHARGED FROM ATLAS BIN
(as received, all percents by weight)

Date	Sample	Size (mm) standard ASTM E-11 designation						Geometric	
		% larger than	% smaller than					Mean	Standard
(1976)	No.[a]	63	63	38.1	19.0	9.5	4.8	diameter	deviation
3-23[b]	2	1.4	98.6	79.9	18.7	14.5	10.3	22.6	2.17
4-22	-	3.2	96.8	85.2	65.5	38.2	22.2	12.4	2.56
5-6	8	0.8	99.3	88.5	67.7	40.4	22.5	11.7	2.46
5-12	9	1.2	98.8	93.9	81.5	58.1	35.1	8.4	2.36
5-20	10	0	100.0	91.1	75.8	58.0	28.6	9.2	2.42
5-25	11	1.1	98.9	93.2	71.0	48.6	26.5	10.2	2.42
6-4	12	3.3	96.7	89.0	73.3	50.9	23.3	10.5	2.47
6-7	13	3.8	96.2	84.3	66.2	41.5	24.5	12.0	2.64
6-14	14	0.1	99.9	95.1	68.9	38.4	25.3	11.1	2.35
Mean[c]		1.7	98.4	88.9	65.4	43.2	24.3	12.0	2.42

Note: First stage shredder grate size - 229 x 229 mm.
Second stage shredder grate size - 76 x 127 mm.

[a] Sample number from Table F-4.

[b] Single stage shredding due to second stage shredder out of service because of bearing failure. Second stage shredder not back in service until March 28, 1976.

[c] Mean does not include single stage shredding data from March 23, 1976.

This method assumes a straight line logarithmic distribution of particle size. The geometric mean diameter is the size at which half the particles are larger than the mean and half are smaller. The geometric standard deviation is the disperison about the mean. A value close to one indicates a small dispersion, while a large value indicates that particles are widely distributed over a large size range.

On April 4, 1976, a large clinker or solidified mass of ash was removed from boiler No. 5. A sample of this clinker was analyzed for ash chemical composition for comparison purposes. These data are presented in Table F-7.

The chemical analysis is not greatly different from the RDF ash except that this clinker had over twice as much Fe_2O_2 than the average for RDF ash (10.31% versus 4.29%). At this point it is assumed that the higher Fe_2O_2 is due to the effect of the coal.

VARIABILITY OF RESULTS

As expected there was considerable variation from day to day in the sample results. Following in Table F-8 is the range of data (maximum and minimum values) encountered, as well as the mean or average value and the standard deviation and confidence interval.

Also listed is the total number of samples in the mean and the standard deviation. The coefficient of variation was also calculated. Coefficient of variation (CV) is a measure of variablility because it expresses the standard deviation as a percent of the mean. As the absolute value of one characteristic increases over that of a different characteristic, the standard deviation may also increase.

A larger standard deviation does not necessarily mean larger variability, and thus CV is a method of accommodating this restriction. The formula for CV is as follows:

$$CV\ (\%) = \frac{S_x}{\overline{X}}\ (100)$$

where $\overline{X}$ = mean; and
S_x = standard deviation.

An analysis of Table F-8 shows that the variability expressed as CV often becomes quite high when the mean values are very low, such as for sulfur, chlorine, nitrogen, ash P_2O_5, and screen size larger than 63 mm.

TABLE F-7. LABORATORY ANALYSIS OF CLINKER ASH REMOVED FROM STOKER BOILER NO. 5, FIRING COAL PLUS RDF

ASTM method D279

(sample removed from boiler April 5, 1976)

Ash analysis	(% by weight)
SiO_2	51.99
Al_2O_3	11.75
Fe_2O_3	10.31
TiO_2	1.04
P_2O_5	0.76
CaO	12.94
MgO	1.98
Na_2O	3.53
K_2O	1.24
OI gain	0.05

TABLE F-8. VARIABILITY OF DAILY VALUES OF CHARACTERISTICS OF RDF DISCHARGED FROM ATLAS BIN (as received, all percents by weight)

Item	Range Maximum value	Range Minimum value	$\overline{X}$ mean	n number of samples	Sx standard deviation	Variability about the mean [±] at 95% confidence coefficient	CV coefficient of variation (%)
Analysis of RDF							
Bulk density (kg/m^3)	157.0	97.0	128.3	14	18.14	10.5	14.1
Heating value (kJ/kg)	15.219	11.475	13.050	14	1,021.6	589.8	7.83
Moisture (%)	31.77	18.65	23.03	14	4.212	2.43	18.29
Ash (%)	22.52	11.12	17.37	14	3.170	1.83	18.25
Volatile matter (%)	59.21	46.57	54.65	14	3.702	2.14	6.77
Fixed carbon (%)	9.34	0.82	4.94	14	2.405	1.39	48.64
Carbon (%)	33.90	26.57	30.86	14	2.224	1.28	7.21
Hydrogen (%)	5.18	4.20	4.77	14	0.324	0.19	6.79
Oxygen (%)	28.32	14.92	22.88	14	3.903	2.25	17.06
Sulfur (%)	0.88	0.23	0.43	14	0.190	0.11	44.77
Chlorine (%)	0.59	0.14	0.24	14	0.110	0.06	45.12
Nitrogen (%)	0.64	0.29	0.42	14	0.106	0.06	25.44
Particle size							
Geometric mean diameter mm[a]	12.4	8.4	10.7	8	1.392	1.2	13.02
Percent larger than 63 mm	3.8	0	1.7	9	1.421	1.1	85.85

(continued)

TABLE F-8. (continued)

Item	Range Maximum value	 Minimum value	$\overline{X}$ mean	n number of samples	Sx standard deviation	Variability about the mean [±] at 95% confidence coefficient	CV coefficient of variation (%)
Analysis of RDF ash							
S_iO_2 (%)	54.10	41.82	48.19	14	4.059	2.34	8.42
Al_2O_3 (%)	18.17	8.45	11.75	14	2.288	1.32	19.47
Fe_2O_3 (%)	8.13	2.91	4.29	14	1.332	7.69	31.04
TiO_2 (%)	1.96	1.07	1.45	14	0.256	0.15	17.74
P_2O_5 (%)	1.25	0.28	0.79	14	0.276	0.16	34.86
CaO (%)	15.48	10.40	12.71	14	1.608	0.93	12.66
MgO (%)	3.19	1.95	2.38	14	0.312	0.18	13.10
Na_2O (%)	5.22	3.46	4.37	14	0.598	0.35	13.68
K_2O (%)	2.26	1.52	1.80	14	0.244	0.14	13.56

a/ Particle size does not include high value on March 23, 1976, due to single stage shredding.

Ash fusion temperatures were not included in Table F-8 because results are not complete for the full 14 days of tests.

The ranking of analysis constituents from the least to the highest variability basis the CV is as follows:

RANKING - LOWEST TO HIGHEST VARIABILITY

RDF	RDF ash
Volatile matter (smallest variability)	SiO_2 (smallest variability)
Hydrogen	CaO
Carbon	MgO
Heating value	K_2O
Geometric mean particle diameter	Na_2O
Bulk density	TiO_2
Oxygen	Al_2O_3
Ash	Fe_2O_3
Moisture	P_2O_5 (highest variability)
Nitrogen	
Sulfur	
Chlorine	
Fixed carbon	
Particle size larger than 63 mm (highest variability)	

MOISTURE FREE AND MOISTURE AND ASH FREE RDF HEATING VALUE

Table F-5 shows the variability of RDF heating value on a moisture as received basis. There is an expected but important relationship of increasing heating value with decreasing moisture and ash content. Therefore, heating value of RDF was calculated on both a moisture free and a moisture and ash free basis.

The statistical standard deviation S_x and the CV were calculated for the daily sample data to determine if variability of RDF heating value changes when expressed on a moisture free or moisture and ash free basis.

Table F-5 shows the results of these calculations. Variability as expressed by CV is highest for moisture free ash and lowest for moisture free heating value. Heating value CV is lower on a moisture free basis than on an as-received basis. However, on a moisture and ash free basis, heating value CV is lower than on an as-received basis, but higher than on the moisture free basis.

The reason for this is not apparent from the ash CV analysis. Ash as received has practically the same CV as moisture. However, the CV for moisture free ash is higher than for as received ash. Therefore, the moisture has a damping effect on ash variability. However, when the higher variability ash is removed from the heating value calculation, the heating value CV increases. Therefore, even though it has the highest variability, the ash is damping the heating value variability.

Figure F-2 shows the relationship between heating value and moisture content and ash content. There was a 71% correlation between heating value and moisture. There was not a good statistical percentage correlation between heating value and ash content due to the scatter in the data.

However, Figure F-2 shows that the Ames RDF heating value is inherently higher than what was observed during the St. Louis tests. The boiler sees RDF heating value as is, with the moisture and ash content that is actually present. The question arises as to whether the higher heating value at Ames is due to the lower moisture and ash content. The answer is yes, but the higher heating value at Ames is not entirely due to lower moisture and ash content as shown below.

	Ames (average of 14 daily samples)	St. Louis (average of 97 daily samples
Moisture (%) (as received)	23.03	26.55
Ash (%) (as received)	17.37	21.71
Heating value (kJ/kg)		
As received	13,050	10,636
Moisture free	16,956	14,494
Moisture and ash free	21,995	20,570

The heating value of the combustibles (moisture and ash free heating value) in the Ames RDF is also higher than the St. Louis RDF. The reasons for this may be answered when processing plant tests are conducted and an analysis for RDF for percent paper, plastic, etc., is conducted.

The question of whether this is a statistical significant difference at a given statistical confidence level is not answered in this report. Since the St. Louis data represent 97 days of tests and the Ames data to date represent only 14 days of tests, it is prudent to wait until more test day data are available at Ames before a statistical difference calculation is made.

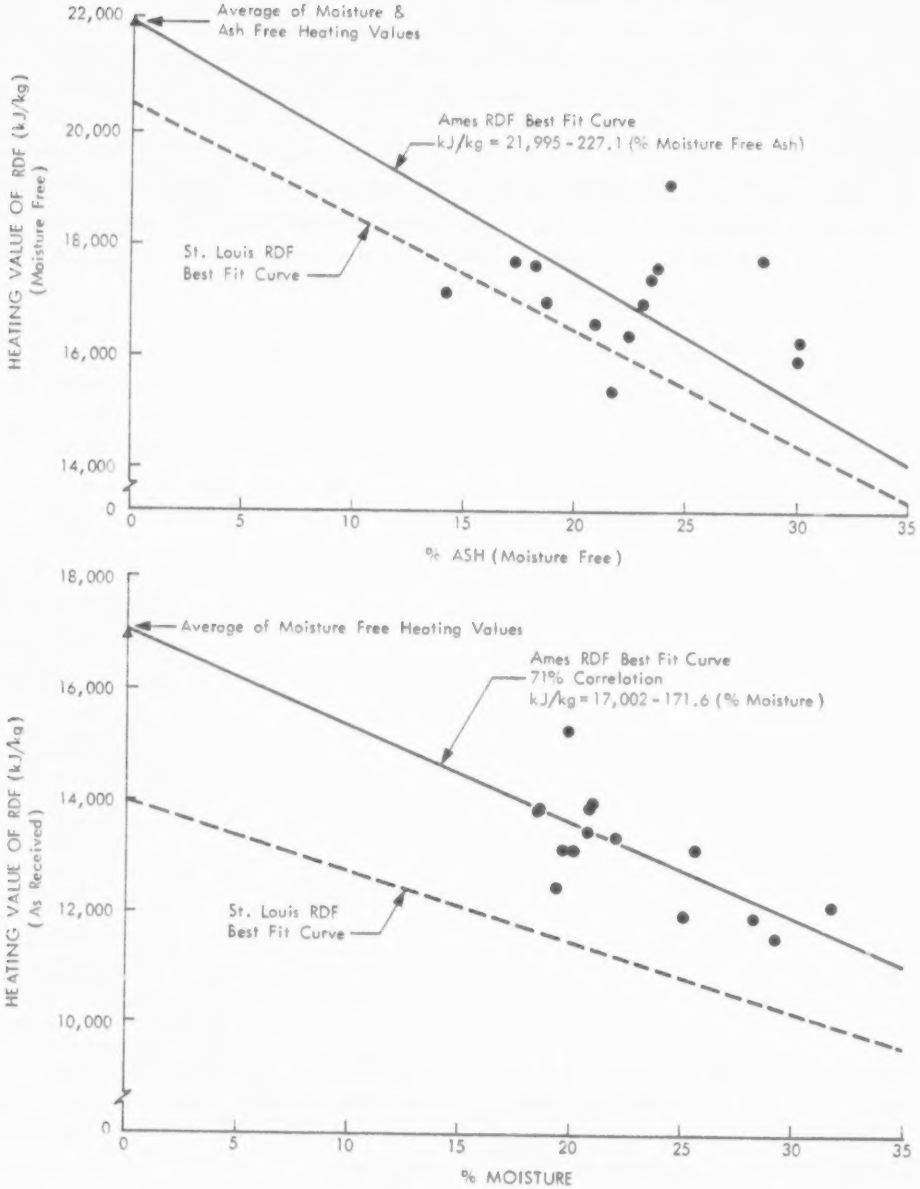


Figure F-2. Heating value of refuse derived fuel (RDF) versus moisture and ash content for daily samples.

APPENDIX G - DESCRIPTION OF MECHANICAL PERFORMANCE OF ATLAS BIN AND PNEUMATIC TRANSPORT LINES

TRANSPORT LINE ELBOWS

Within a relatively short time after the start-up of refuse burning, the power plant personnel noticed that severe wear was occurring in the transport lines between the Atlas Storage Bin and the various boilers. This severe wear was a particular problem in the transport line elbows since this wear created holes in the transport line elbows.

The original transport line elbows were made of mild steel and were referred to as "wearback" elbows. Since these "wearback" elbows were original equipment, a cost per elbow is not readily available. Due to the abrasive wear of the processed refuse, these elbows were found to have a life of only approximately 1,000 hours.

In an attempt to increase the life of these "wearback" elbows, power plant personnel hard-rodded the wear susceptible surfaces. This hard-rodding process consisted of placing a bead of weld metal in a cross-hatched pattern on the surface in question. A 6.35 mm to a 12.7 mm square was the cross-hatched pattern spacing. This process added about $100.00 to the cost of the "wearback" elbows and increased the elbows' life to approximately 1,700 hours.

The power plant then purchased another type of transport line elbow known as "astroloy". It is unknown what specific material these elbows were constructed from. These elbows cost $160.00 per elbow and had an operating life of approximately 650 hours.

At the present time, the power plant is using a transport line elbow known as "Castalloy CR 25". The material from which these elbows are constructed is unknown, except that their hardness is 500 Bhn. These elbows cost $230.00 per elbow and have performed for better than 2,000 hours with no sign of severe wear. Due to the promising performance of these "Castalloy CR 25" elbows, the power plant personnel are installing the same type elbows in the transport line between the processing plant and the Atlas Storage Bin. These larger elbows will cost approximately $495.00 per elbow.

SWEEP SYSTEM SHUTDOWN

On June 16, 1976, the sweep system in the Atlas Storage Bin experienced a mechanical failure which resulted in the shutdown of refuse removal from the Atlas Storage Bin and necessitated extensive repairs.

The following is a consensus of the events leading up to the aforementioned shutdown. All details referred to are found on Atlas Systems drawing 3000053.

Due to the inherent vibrations in the system and possibly a maintenance oversight, the lock screw on the thrust wheel assembly loosened on at least one and likely more than one. Once the lock screw had loosened, the adjusting screw could back off. This combination of events would allow the sweep ring, which was originally set up and designed to operate in a circular path, to travel in an elliptical path which would become more pronounced as the adjusting screw backed off further. At some point in time, the elliptical path became such that at least one drag ring sweep scraper was able to hook itself on a structural element. Since the drag ring was under power and the scraper was hooked, something had to give and in this case the scraper was the weaker element. When the scraper broke, it wedged itself between the bin floor and the suspension rollers which support the weight of the sweep ring. The weight supported by the suspension roller was too large to allow the roller to roll over the broken scraper and the power on the drag ring allowed at least one suspension roller assembly to be torn from its brackets on the drag ring although two suspension roller assemblies were replaced. Once the suspension roller was removed, the thrust wheel assembly would be forced to carry a vertical load for which it was not designed. This vertical load then sheared the set pin on the bottom of the thrust roller assembly and also drove the lower thrust roller off the thrust roller assembly. Once this roller was off, the drag ring could move down due to the loss of the suspension roller and move in due to the imbalance of the thrust roller assembly. With the drag ring in this configuration, subsequent thrust roller assemblies would experience an undesigned vertical load due to the drag ring's own weight and power. A total of eight thrust roller assemblies were replaced. As the thrust rollers failed, the drag ring came in contact with what can be referred to as structural piers in the Atlas Storage Bin. The drag ring then sheared material from these structural piers until the load to do this exceeded the overload setting and shut the system down.

SWEEP DRIVE SYSTEM SHUTDOWN

On August 2, 1976, the sweep drive system in the Atlas Storage Bin experienced a mechanical failure which resulted in the shutdown of the refuse removal from the bin.

The following is a consensus of the events leading up to the aforementioned shutdown. All details referred to can be found on Atlas Systems drawing 3500055 with the exception of an idler tension maintaining cable, which is not shown.

The mechanical failure occurred when the chain in the chain drive which transferred power from the DC motor's drive shaft to the cycloidal sprocket drive shaft fell off its sprockets. The cycloidal sprocket drives the sweep drag chain. The chain fell off its sprockets after a cable which maintained tension on the idler sprocket broke. The cable broke due to the fatigue type shock loadings imposed when the idler sprocket would move at its pinned supports. This movement was possible due to the elongation of the pin's hole. This elongation of the holes was due to a misalignment of the chain between the DC motor drive shaft's sprocket, the cycloidal drive shaft's sprocket, and the idler sprocket which put an increased loading on the bracket supports. The effects of this misalignment were accelerated by the use of the manual mode of operation for the refuse removal system rather than the automatic mode of operation as the system was designed to function. Power plant personnel found that the automatic mode failed to supply the necessary flow rates and consequently the manual mode was used. The misalignment of the chain was due to a failure to set the spacers on the idler sprocket correctly. This failure was considered to be the proximate cause of the shutdown on August 2, 1976.

ATLAS STORAGE BIN CONTROL SYSTEM MODIFICATIONS

In order to reduce wear in the Atlas Storage Bin's refuse removal system and to be able to provide a uniform volume flow of refuse from the Atlas Storage Bin, the Ames power plant's personnel modified the existing control system. This modified system was first put into operation on October 8, 1976.

To be able to understand the need for the modifications that were made, a brief description of the pre-modified control system will be made.

The control system consisted of three control modes; manual, automatic, and timer. In the manual mode, the operator has direct control over the sweep and outfeed conveyor speeds. In this mode, the set point, outfeed conveyor speed, and material depth inputs are ignored by the system. Because of the variable nature of the refuse stored in the bin, it is very difficult to maintain a desired flow rate in the manual mode without running the sweep at an accelerated rate and overfilling the outfeed conveyor troughs. Running the sweep too fast can cause system overload and accelerated wear on the system components which should be avoided.

The automatic mode is a closed loop where the logic control unit is provided a setpoint by the operator which may be volumetric rate or level in the outfeed conveyor. This setpoint is compared to the achieved material flow rate or level into correspondence with the setpoint by increasing or decreasing the sweep speed.

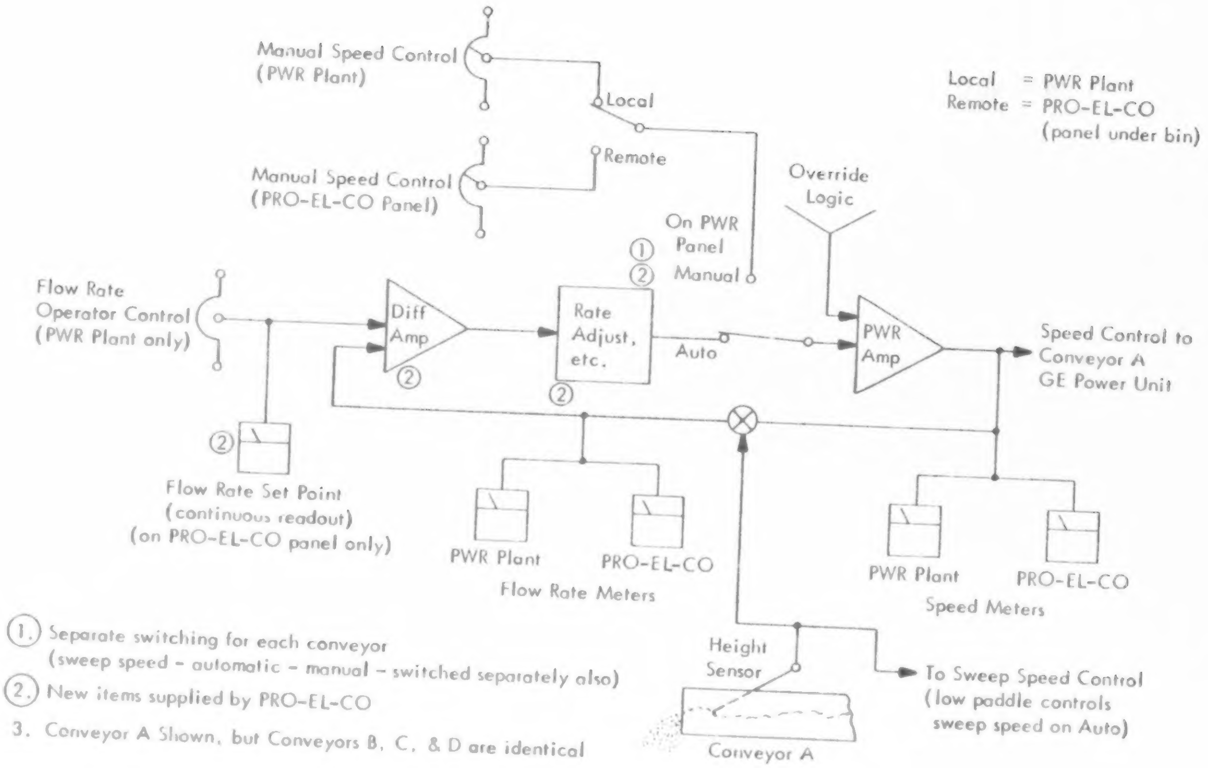
The timer mode is a safety device to prevent the sweep buckets strings from becoming buried in the bin. Whenever the sweep speed drops below a preset speed, usually 5 to 15%, the control system reverts to the timer mode and beyond the operator's control. In this mode, the sweep is operated for approximately 3 out of every 15 minutes at approximately 20% speed. This will allow the sweep bucket strings to work to the outside of any new material being fed into the bin or any material falling from an undercut.

Ames power plant personnel discovered from operating the Atlas Storage Bin that the automatic mode failed to deliver a uniform volume flow of refuse whenever the bin was very full or nearly empty. When the bin was very full, very little sweep movement was required to fill the outfeed conveyor troughs. As this material would pass under the level sensor, the control unit would sense a full trough and stop the sweep. Then the trough emptied, the control unit would sense the empty trough and send the sweep speed to its maximum of 200% until the level sensed a full trough again. This oscillation of the sweep was highly undesirable. When the bin was nearly empty, only a few of the sweep buckets would actually contact the refuse pile and consequently the outfeed conveyor would sense intermediately a full trough and then an emptied trough as the bucket's contents passed under the level sensor. This meant that the sweep would again oscillate between 0 and 200% sweep speeds.

As an intermediate solution, the Ames power plant personnel operated the system in the manual mode rather than the intended automatic mode. In the manual mode, the sweep speed was set at 150% resulting in the overfill of the outfeed conveyor troughs but assuring a full trough at all times. Thus, the outfeed conveyor speed could be set to obtain a given volume flow rate. This solution was not desirable since with the sweep speed so high, any wear in the sweep system components was accelerated.

The modification made to the control system was the addition of a circuit to allow for automatic outfeed conveyor speed control. Now the operator sets a desired flow rate and the control circuit automatically senses the outfeed conveyor trough height and monitors the outfeed conveyor speed and sweep speed. If the level should change, the conveyor speed would immediately be increased or decreased to meet the flow rate requirement and subsequently the sweep speed would increase or decrease. The advantage is in a quick response to fluctuations in trough material level. The disadvantage is in accelerated wear in the outfeed conveyor system. Initial operation has shown that very favorable volume flow rate control is maintained with the sweep speed at about 80% with little fluctuation. To aid the sweep system in maintaining sufficient material in the outfeed conveyor, the reference level in the outfeed conveyors has been reduced from 0.33 m originally, to 0.18 m and finally to 0.13 m. This modification does cause the outfeed conveyor to operate at a higher speed to maintain a given volume flow rate. To avoid having the system go into the timer mode and out of the operator's control during periods of slow sweep speed, the power plant personnel have altered the sweep speed control so that the minimum sweep speed is 30% whenever the sweep system is in operation.

Figure G-1 is a block diagram of the control modification drawn from a sketch supplied by Mr. Harold Alt of the Ames power plant's electrical department. Figure G-2 is a block diagram of the overall control system before the modifications shown if Figure G-1 were made.


Manual Speed Control (PWR Plant)
Local
Remote
Manual Speed Control (PRO-EL-CO Panel)
Local = PWR Plant
Remote = PRO-EL-CO (panel under bin)
Override Logic
On PWR Panel
Manual
① ②
Flow Rate Operator Control (PWR Plant only)
Diff Amp
②
Rate Adjust, etc.
②
Auto
PWR Amp
Speed Control to Conveyor A GE Power Unit
②
Flow Rate Set Point (continuous readout) (on PRO-EL-CO panel only)
PWR Plant
PRO-EL-CO
Flow Rate Meters
PWR Plant
PRO-EL-CO
Speed Meters
Height Sensor
Conveyor A
To Sweep Speed Control (low paddle controls sweep speed on Auto)

(1.) Separate switching for each conveyor (sweep speed - automatic - manual - switched separately also)

(2.) New items supplied by PRO-EL-CO

3. Conveyor A Shown, but Conveyors B, C, & D are identical

Figure G-1. Conveyor speed control addition for Atlas control system.

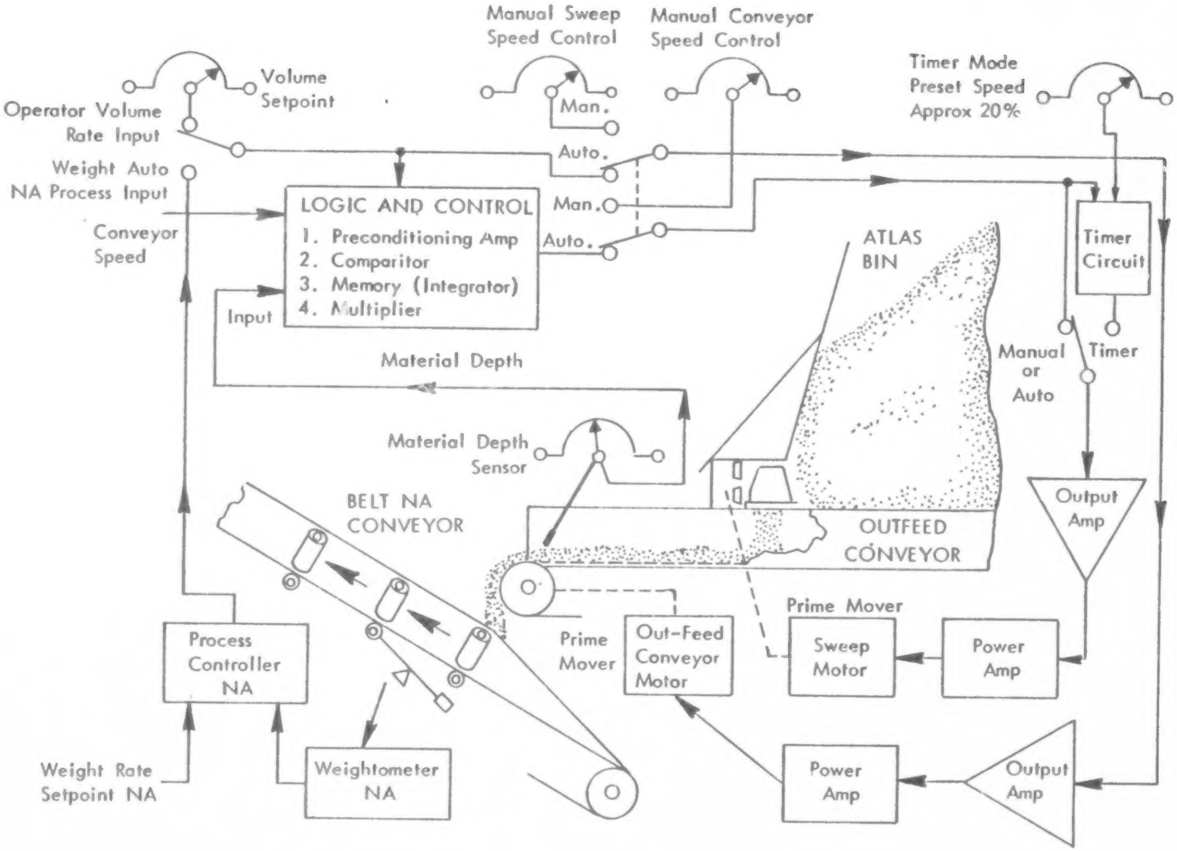


Figure G-2. Overall system block diagram.